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Evaluation of Emission Control Devices at Waferboard Plants

Midwest Research Inst., Cary, NC

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This document discusses emissions from wood chip dryers and the candidate control devices that should be considered in a best available control technology analysis. Specifically, the document characterizes wood chip dryer effluents and presents a general description, pollutant removal efficiencies, factors affecting performance, and cost for the wet electrostatic precipitator and the electrified filter bed.

The document also presents information on controlling formaldehyde emissions from the press vents.

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EVALUATION OF EMISSION CONTROL DEVICES AT WAFERBOARD PLANTS

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FINAL REPORT

EVALUATION OF EMISSION CONTROL DEVICES AT WAFERBOARD PLANTS

CONTROL TECHNOLOGY CENTER

SPONSORED BY:

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DISCLAIMER

This document presents an engineering evaluation of control options for wood chip dryers. Specifically, the document discusses the use of electrified filter beds and wet electrostatic precipitators for control of wood chip dryer effluents. Also, emission reduction by reduced temperature drying is discussed. The EPA does not represent that this document comprehensively sets forth all of the procedures for wood chip dryer and control device operation, or that it describes applicable legal requirements which vary among the States.

Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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PREFACE

The wood chip dryer engineering assistance project was funded by EPA's Control Technology Center (CTC). The CTC was established by EPA's Office of Research and Development (ORD) and Office of Air Quality Planning and Standards (OAQPS) to provide technical assistance to State and local air pollution control agencies. Three levels of assistance can be accessed through the CTC. First, a CTC HOTLINE provides telephone assistance on matters relating to air pollution control technology. Second, more in-depth engineering assistance can be provided when appropriate. Third, the CTC can provide technical assistance through publication of technical guidance documents, development of personal computer software, and presentation of workshops on control technology matters.

The engineering assistance projects, such as this one, focus on topics of national or regional interest that are identified through contacts with State and local agencies. In this case, the CTC was contacted by the State of Colorado Department of Health, Air Pollution Control Division, with a request for information about control of wood chip dryer emissions from waferboard plants. Specifically, the agency requested available information on the use of the electrified filter bed and wet electrostatic precipitator for control of wood chip dryer effluents. As a result, EPA's Emission Standards Division (ESD) contracted with Midwest Research Institute (MRI) to conduct an engineering evaluation of these control options. This report presents the results of that evaluation. The report discusses the composition of wood, design and operation of the control devices, costs, and factors affecting performance.

TABLE OF CONTENTS

		Page
LIST OF FIGURES		vii
LIST OF TABLES		viii
SECTION 1.0	INTRODUCTION	1
SECTION 2.0	SUMMARY AND CONCLUSIONS	3
	2.1 CHARACTERIZATION OF EMISSIONS	3
	2.2 EMISSION CONTROLS	3
	2.3 PRESS VENT EMISSIONS	4
SECTION 3.0	GENERAL PROCESS DESCRIPTION	5
SECTION 4.0	EXTRACTABLE ORGANICS IN WOOD	7
SECTION 5.0	CHARACTERIZATION OF WOOD CHIP DRYER EFLUENTS	11
	5.1 TURPENES	11
	5.2 RESINS AND FATTY ACIDS	13
	5.3 PRODUCTS OF THERMAL DECOMPOSITION	14
SECTION 6.0	AEROSOL FORMATION	15
SECTION 7.0	EMISSION CONTROLS	18
	7.1 ELECTRIFIED FILTER BED	19
	7.1.1 General Description	19
	7.1.2 Pollutant Removal Efficiencies	26
	7.1.3 Factors Affecting Performance and Suitability	26
	7.1.4 Costs	30
	7.2 WET ELECTROSTATIC PRECIPITATORS	30
	7.2.1 General Description	30
	7.2.2 Pollutant Removal Efficiencies	32
	7.2.3 Factors Affecting Performance and Suitability	37
	7.2.4 Costs	39
SECTION 8.0	LOW/REDUCED TEMPERATURE DRYING	41
	8.1 DRYER TEMPERATURE VERSUS EMISSIONS	41
	8.2 DRYER LOADING VERSUS EMISSIONS	43
	8.3 PRODUCTIZATION 3PHV DRYER	43

TABLE OF CONTENTS (continued)

SECTION 9.0	PRESS VENTS	48
SECTION 10.0	REFERENCES	52
APPENDIX A.	EFB AND ESP USER LIST	A-1
APPENDIX B.	WEYERHAUSER'S EFB TEST DATA	B-1
APPENDIX C.	GEORGIA-PACIFIC'S ESP TEST DATA	C-1
APPENDIX D.	PRODUCTIZATION 3PHV DRYER PATENT	D-1
APPENDIX E.	MEMORANDUM: FORMALDEHYDE FROM WAFERBOARD PRESS OPERATIONS	E-1

LIST OF FIGURES

		Page
Figure 1.	Minimum theoretical particle size formed for oleic acid at various supersaturations.....	16
Figure 2.	Theoretical vapor pressure of small particles of oleic acid.....	16
Figure 3.	Electrified filter bed system.....	20
Figure 4.	Ionizer and gravel bed assembly.....	21
Figure 5.	Gravel bed schematic.....	22
Figure 6.	Gravel bed flow controller.....	24
Figure 7.	Disengagement chamber.....	25
Figure 8.	Bag filter.....	27
Figure 9.	Wet ESP module equipped with traveling spray system.....	33
Figure 10.	Productization 3PHV rotary drum dryer.....	44
Figure 11.	Flow comparison of conventional triple pass dryer and 3PHV drum dryer.....	45

LIST OF TABLES

		Page
TABLE 1.	ETHER-SOLUBLE EXTRACTIVES CONTENT OF COMMON HARDWOODS....	8
TABLE 2.	ETHER-SOLUBLE EXTRACTIVES CONTENT OF COMMON SOFTWOODS....	9
TABLE 3.	TURPENTINE CONTENT OF WOOD SPECIES.....	12
TABLE 4.	EFFICIENCY SUMMARY OF WEYERHAEUSER'S EFB IN MONCURE, NORTH CAROLINA, FOR CONTROL OF WOOD PARTICLE DRYER EXHAUST TEST PERFORMED OCTOBER 20, 1988.....	28
TABLE 5.	EFFICIENCY SUMMARY OF EFB FOR CONTROL OF WOOD PARTICLE DRYER EXHAUST TEST PERFORMED FEBRUARY 14-17, 1989.....	29
TABLE 6.	EFB COST EVALUATION.....	31
TABLE 7.	EFFICIENCY SUMMARY OF GEORGIA-PACIFIC's WET ESP IN DUDLEY, NORTH CAROLINA, FOR CONTROL OF WOOD CHIP DRYER EXHAUST TEST PERFORMED SEPTEMBER 1983.....	34
TABLE 8.	EFFICIENCY SUMMARY OF GEORGIA-PACIFIC's WET ESP IN SKIPPERS, VIRGINIA, FOR CONTROL OF WOOD CHIP DRYER EXHUAST TEST PERFORMED APRIL 20, 1989.....	35
TABLE 9.	EFFICIENCY SUMMARY OF GEORGIA-PACIFIC's WET ESP IN WOODLAND, MAINE, FOR CONTROL OF WOOD CHIP DRYER EXHAUST TEST PERFORMED OCTOBER 25, 1988.....	36
TABLE 10.	CAPITAL AND OPERATING COST OF WET ESP.....	40
TABLE 11.	INCREASE OF PARTICULATE MASS RATE WITH INCREASING INLET TEMPERATURE.....	42
TABLE 12.	VOC EMISSION FACTORS FOR PRESS VENTS.....	50

1.0 INTRODUCTION

The U. S. Environmental Protection Agency (EPA), Office of Air Quality Planning and Standards (OAQPS), is involved in responding to requests from EPA Regional Offices and from State and local air pollution control agencies to investigate air pollutant emission sources and the control technologies that can be applied to reduce these air pollutants. These requests are sometimes received at the Control Technology Center (CTC) and require quick evaluations of air pollution emission sources and the control technologies that can be used to reduce the emissions from these sources. These emission sources may be significant enough to warrant national standards or guidelines. Accordingly, OAQPS studies these sources to determine whether they warrant further review and possibly national standards development.

The State of Colorado Department of Health, Air Pollution Control Division, has received complaints of eye and lung irritation from residents near a waferboard manufacturing plant located outside of Olathe, Colorado. The State requested assistance from the CTC in determining possible emission sources within the plant and assessing potential controls for those emissions. The CTC report published in September 1987 recommended that additional work be done in determining the effectiveness of a wet electrostatic precipitator (ESP), a dry type of control system such as an electrified filter bed (EFB), and any other promising control methods.

Recently, the State of Colorado Air Pollution Control Division requested additional assistance from the CTC in determining the effectiveness of control devices for emissions from wood chip dryers in waferboard plants. The pollutants of concern are particulate matter, formaldehyde, other wood decomposition products, and volatile organic compounds (VOC). The review conducted by Midwest Research Institute (MRI) for the CTC focuses on the evaluation of EFB's and wet ESP's. Colorado and several other States also have expressed an interest in a review of press vent emissions.

This report presents a general process description of waferboard production (Section 3.0), an analysis of the extractable organics in wood

(Section 4.0), a characterization of wood chip dryer effluents (Section 5.0), a discussion on aerosol formation (Section 6.0), an evaluation of emission control options (Section 7.0), and a review of the available information on press vent emissions (Section 8.0).

2.0 SUMMARY AND CONCLUSIONS

2.1 CHARACTERIZATION OF EMISSIONS

It is difficult, with the limited data available, to characterize wood chip dryer effluents. Emissions from wood chip dryers are composed of organic compounds from the extractable portion of the wood, wood dust, products of combustion, and fly ash. Wood species, dryer temperature, dryer loading rate, previous drying history of the wood, and other factors significantly affect the composition of wood chip dryer effluents. An understanding of the relationships between these factors and the composition of wood chip dryer exhaust emissions would require comprehensive parametric test data that currently are not available.

2.2 EMISSION CONTROLS

The two devices used to control wood chip dryer effluents are the electrified filter bed (EFB) and the wet electrostatic precipitator (ESP). These are the devices most likely to be considered in a best available control technology analysis.

The EFB has been a popular control device in the wood products industry for controlling dryer effluent gases. Approximately 40 units are in use to control emissions from waferboard and other composite material dryers. Because the EFB is a dry control device, it offers the convenience of producing a dry waste stream that requires disposal but no further treatment. The current data show EFB particulate removal efficiency to be 79 to 94 percent. Total hydrocarbon removals are expected to be much lower (10 to 20 percent) because the EFB cannot electrostatically remove any material that is not a solid or that it cannot condense. One of the more prevalent problems associated with the EFB is the difficulty it sometimes has with the extremely sticky, hydrocarbon-laden gas streams generated from the drying of pine and other softwood species. Hydrocarbons condensing in the unit collect on the ionizer and on the surface of the gravel, reducing the efficiency of the unit and requiring frequent shutdowns and cleaning of the unit. For this reason, the EFB is more suited for controlling effluents generated from the drying of hardwoods and other low-resin-content species.

Wet ESP's are used to control effluent gas streams containing particulate and sticky, condensible hydrocarbon pollutants. These devices have been used extensively in various industrial applications (e.g., aluminum pot lines, carbon anode baking furnaces, and wool fiberglass plants) to control particulate matter. Five wet ESP's are in service to control wood chip dryer effluents in the waferboard and other wood composite material industries. Tests indicate that the particulate collection efficiency of a wet ESP is between 90 and 98 percent. Wet ESP's have a demonstrated removal efficiency of 70 percent for total gaseous nonmethane organic (TGNMO) compounds. Wet ESP's are better than EFB's for the control of sticky, hydrocarbon-laden wood chip dryer effluent streams. A disadvantage of wet ESP's is that their capital and operating costs are higher than for EFB's. Also, plants using wet ESP's must have the ability to dispose or consume within the plant their spent spray water.

2.3 PRESS VENT EMISSIONS

Emissions from the press vents result as the resinated chips are heated in the press. Formaldehyde and other VOC's contained in the resin and wood chips evaporate and exit through the press vents. Three factors were identified that affect formaldehyde emissions from press vents: (a) the excess formaldehyde content of the resin, (b) the amount of resin used, and (c) the press temperature. The data indicate that from 5 to 15 percent of the excess formaldehyde in a panelboard is emitted during the pressing and board cooling operations. Analysis of the available data on press vent emissions suggests that use of methyldiisocyanate resins (MDI) instead of phenol/formaldehyde resins would result in a 50 percent reduction of VOC emissions and a 90 percent reduction of formaldehyde emissions.

3.0 GENERAL PROCESS DESCRIPTION

The fundamental processing steps involved in the production of waferboard, oriented strandboard (OSB), and related panelboard products are described below. Some processing techniques will vary among different plants and product lines.

Logs that go to the waferboard plant are cut to 100 inches in length by a slasher saw and put into a hot pond. The hot pond, maintained at a temperature between 80° and 120°F (18° to 43°C), pretreats the logs for waferizing by thawing them during winter operations. The logs are debarked and carried to stationary slasher saws where they are cut into 33-inch lengths in preparation for the waferizer. The waferizer slices the logs into wafers about 0.028 inch thick. The wafers are then conveyed to the wet wafer storage bin to await processing through the dryer(s). The dryer(s) is normally fired by wood wastes from the plant and occasionally by oil. When methylenediphenyldiisocyanate (MDI) resin is utilized in the blending process, the wafers are dried until their moisture is 8 to 10 percent. When phenolic resin is used in the blending process, the wafers are dried to 4 to 5 percent moisture. The dried wafers are pneumatically conveyed from the dryer, separated from the gas stream at the primary cyclone, and transferred onto a rotary screen. The gas stream continues through a multiclone, I.D. fan, and sometimes a tertiary pollution control device (i.e., EFB, wet ESP) and then is discharged through a stack into the atmosphere. A rotary screen further classifies the wafers. Undesired material is sent to a fuel preparation system for the dryer burner and the screened wafers are stored in dry bins. The wafers are then conveyed to the blender where they are blended with the resin. The resinated wafers then go to the formers where they are metered out on a continuously moving screen system. The continuous formed mat is then separated into desired lengths by a traveling saw, passed to the accumulating loader, and sent to the press. The press applies heat and pressure to activate the resin and bond the wafers into a solid sheet of waferboard. The bonded sheet is then trimmed to final dimensions, sprayed on the edges with a protective coating, and packaged for shipping.

For the purposes of this study, the emission points of interest are the wood chip dryers and the presses.

4.0 EXTRACTABLE ORGANICS IN WOOD

It is customary in the wood products industry to differentiate the wood tissue components from the extractive components of wood. The extractive components include the substances that are soluble in neutral organic solvents or are volatile with steam. The term extractive components embraces a wide range of chemical compounds. No single species of wood contains all the possible compounds or even all the different classes of compounds. This discussion will focus on the rather large group of materials generally referred to as "resins." Wood resin will be generally defined as those hydrophobic substances soluble in neutral, nonpolar organic solvents. This will include terpenes, resin acids, fatty acids and esters, and various alcohols, hydrocarbons, and other neutral compounds associated with these materials.

As shown in Table 1, the resin content of hardwoods varies greatly from one species to another. The majority of the hardwoods listed contain considerably less than 1 percent resin by weight. From Table 2, it is apparent that softwoods contain considerably more resin than hardwoods. Resin contents of at least 1 percent have been reported for almost every species of softwood listed; however, the pines have by far the highest resin content. The most striking difference between hardwood and softwood resin is the almost complete absence of resin acids in hardwood resins. In contrast, resin acids are a major component of pine and spruce resin, generally accounting for 30 to 40 percent of the weight of the extract.[1]

The major component of both hardwood and softwood resin is fatty acid. In softwoods, the fatty acids make up 40 to 65 percent of the resin, while in hardwoods they account for 60 to 90 percent.[1] In fresh wood samples, the bulk of the fatty acids are usually present as esters.

Certain conifers secrete a viscous liquid called oleoresin (essentially of a solution of a resin in a volatile oil) when the tree is wounded. In the case of pine oleoresin, the volatile oil, or turpentine, constitutes about 25 percent of the weight of the oleoresin.[1] The nonvolatile part of the oleoresin consists mainly of resin acids. Both the volatile oil and the resin acids belong to the terpenoids, a group of compounds derived from a family of hydrocarbons known as the terpenes. As

TABLE 1. ETHER-SOLUBLE EXTRACTIVES CONTENT OF COMMON HARDWOODS[1]

Species	Ether-soluble, percent (w/w) of whole wood	Sapwood	Heartwood
Sugar maple	0.22-0.89	0.23-0.26	0.25-0.33
Red maple	--	0.16-0.51	0.21-0.31
Yellow birch	0.43-1.43	0.36-0.88	0.30-1.18
Paper birch	1.5-3.52	0.79-2.97	2.19-3.89
American beech	0.3-0.86	0.19-0.26	0.38-0.57
White ash	--	0.88-1.17	0.45-0.46
Black tupelo	0.27-0.40	0.44	0.54
Water tupelo	0.34	0.95	0.88
Sweetgum	0.22-0.49	--	--
Eastern cottonwood	0.3-0.4	--	--
Bigtooth aspen	0.86-2.7	--	--
Yellow poplar	--	0.13-0.27	0.43-0.58
White oak	--	0.46-0.65	0.62-0.71
Black willow	0.3	--	--
American basswood	0.89-13.2	--	--
American elm	0.28	--	--

TABLE 2. ETHER-SOLUBLE EXTRACTIVES CONTENT OF COMMON SOFTWOODS[1]

Species	Ether-soluble, percent (w/w) of whole wood	Sapwood	Heartwood
Balsam fir	1.0-1.8	0.95	0.74-1.18
White fir	0.23	0.20	0.25
Douglas fir	0.3-2.6	0.4	1.0
Eastern hemlock	0.2-1.2	--	--
Western hemlock	0.3-1.3	0.2-0.5	0.2-1.0
Eastern larch	1.3	--	--
Western larch	0.72-0.93	--	--
Western redcedar	0.3-2.5	--	--
Incense cedar	3.33-4.90	0.67	4.78
Yellow cedar	1.36-3.34	1.00	1.32
White spruce	0.4-2.1	--	--
Black spruce	0.6-1.0	--	--
Red spruce	--	0.6-1.2	0.8-1.5
Jack pine	1.9-4.3	1.6	5.2
Shortleaf pine	1.1-2.3	2.6-3.8	3.9-13.3
Longleaf pine	2.1-9.2	1.4-2.7	3.6-20.3
Ponderosa pine	6.5-9.6	3.2-4.8	2.7-9.9
Monterey pine	--	0.5-1.2	2.0-6.8
Eastern white pine	5.9	5.46	3.62
Slash pine	1.4-15.2	--	--

might be expected, the volatile oils of the pines have been studied more than oils of other species because of their commercial importance. Gum turpentine is obtained by steam distillation of the oleoresin, and wood turpentine is usually obtained by steam distillation or solvent extraction of pine heartwood. Gum and wood turpentine may have very different compositions. For example, the gum turpentine from pine was found to contain approximately 65 percent α-pinene and 35 percent β-pinene, while the wood turpentine consisted of 80 percent α-pinene, 10 percent limonine, 8 percent α-terpinene, and very little β-pinene.[1] Most of the pines from the southeastern United States produce turpentines comprised chiefly of α-pinene and β-pinene, the former predominating.

5.0 CHARACTERIZATION OF WOOD CHIP DRYER EFFLUENTS

Emissions from direct-fired wood chip dryers are composed of organic compounds evaporated from the extractable portion of the wood, wood dust, products of combustion, and fly ash. The organic portion of the emissions can be categorized as: (1) turpentine, (2) resin and fatty acids, and (3) combustion and pryolysis products. Wood species, dryer temperature, dryer loading rate, previous drying history of the wood, and other factors significantly effect the composition of wood chip dryer effluents. An understanding of the relationships between these factors and the composition of wood chip dryer exhaust emissions would require comprehensive parametric test data that currently are not available.

5.1 TERPENES

Turpentine is a major constituent of many softwood species. The amount present in numerous softwood species can be found in Table 3. The actual amount of turpentine present in the wood being dried depends on the wood species and on the amount of drying the wood has undergone. Green softwood contains the most turpentines. The amount of turpentine in the wood will decrease as it dries, either in a drying process or during storage. A 50 percent loss of turpentine from wood has been reported during storage of wood chips in an open pile for 1 week.[2]

Terpenes have boiling points of about 155°C (311°F). Nearly all of the turpentine material contained in green wood chips is removed during drying because the boiling points of the terpenes are below the dryer air temperatere. Terpenes will remain in the vapor state in the dryer and when emitted to the atmosphere and, thus, will not contribute to particulate emissions or the opacity of dryer plumes.

Terpenes are among the most photochemically reactive compounds. Although terpenes have been shown to react rapidly in the presence of NO_x and ultraviolet light to form ozone, they are inefficient ozone producers. Secondary reactions with ozone result in oxidation of terpenes that block further photochemical reactions. Although the reaction rates for terpenes are high, the net ozone yield is low.

TABLE 3. TURPENTINE CONTENT OF WOOD SPECIES[2]

Species	Turpentine, gal/ton dry wood	Species	Turpentine, gal/ton dry wood
Bahama pine	1.09	Ponderosa pine	0.98
Balsam fir	0.93	Red pine	0.99
Black spruce	0.08	Sand pine	0.48
Douglas fir		Short leaf pine	0.89
Washington	1.05	Sitka spruce	0.12
Canada	0.19	Splash pine	1.40
Eastern white pine	1.05	Spruce pine	1.17
Engelman spruce	0.18	Subalpine fir	0.15
Grand fir	ND	Sugar pine	0.66
Jack pine	0.81	Tamarack	0.12
Hemlock		Virginia pine (scrub pine)	5.86
Eastern	ND	White fir	ND
Mountain	ND	Western larch	0.66
Western	ND	Western red cedar	ND
Loblolly pine	0.97	Western white pine	0.24
Lodgepole pine	0.54	White spruce	0.16
Long leaf pine	4.06		
Pacific silver fir	ND		
Noble fir	ND		
Pitch pine (yellow or Southern pine)	1.12		
Pond pine	0.92		

ND = None detected.

5.2 RESINS AND FATTY ACIDS

Resins and fatty acids, otherwise known as pitch, are also natural constituents of wood. The amount of pitch in the wood varies with species, with softwood species containing a large amount and hardwood species containing very little. Fatty acids contained in southern wood species consist primarily of oleic and linoleic acids. The resin acids are principally levopimaratic, palustratic, and abietic acids.[2]

As with the terpenes, resin and fatty acids also vaporize during drying. Fatty acids have boiling points between 320°C and 370°C (608° to 698°F). Resin acid boiling points are even higher.[2] Vaporization of pitch increases with higher drying temperatures, higher airflow through the dryer, and higher pitch content of the wood. Unlike the terpenes, vaporized resins and fatty acids cool and condense as they exit the dryer to form an aerosol that produces the blue haze associated with wood product dryer emissions. Aerosol formation is discussed further in Section 6.0. Analyses of the condensible fractions of veneer dryer emissions have been conducted. The same fatty and resin acids found in wood extractives were found in the veneer dryer emissions. The amount of each chemical species varied greatly depending upon the wood species dried and the point at which the dryer was sampled. Slightly more resin acids than fatty acids were found in most of the samples.[2]

A study was done recently by the National Council of the Paper Industry for Air and Stream Improvements (NCASI) at eight panelboard plants whose dryers produced furnish for particleboard, waferboard, OSB, and fiberboard manufacture. Emissions of condensable organic material, defined as the material capable of passing a filter at 250°F and condensing at 70°F, ranged between 0.04 and 2.5 lb/ton of product.[3] Total particulate and condensable organic material emission rates ranged from 0.8 to 6.5 lb/ton of product. The concentration of these materials in the exit gas and hence the emission rate was influenced by the temperature of the gases entering the dryer, the species being dried, and the amount of drying the wood had undergone.

5.3 PRODUCTS OF THERMAL DECOMPOSITION

The reactions that occur during the thermal decomposition of wood result in the formation of a large number of chemical compounds. More than 200 compounds isolated after pyrolysis of resinous woods have been identified, and, undoubtedly, many others not yet identified are present. Although the origin of all the products of thermal decomposition cannot be assigned to individual components of the original wood, it is known that each of the major components yields characteristic decomposition products. Thus, furans result from pyrolysis of pentoses, and an assortment of aromatic substances from pyrolysis of lignin. The origin of much of the acetic acid is attributed to the acetyl groups in the wood. At the elevated temperatures, secondary reactions of many types take place. The final products represent not only a wide variety of substances, but also the varying proportions of these substances depend upon the conditions during the decomposition reactions.

Wood remains stable when heated up to about 100°C (212°F), except for loss of hydroscopic water. As the temperature increases further, carbon dioxide, carbon monoxide, hydrogen, and water are formed by the chemical decomposition of the wood constituents. Between 100° and 250°C (212° to 480°F) decomposition causes the wood to darken. At higher temperatures, up to 500°C (850°F), carbonization occurs and additional volatile materials are lost.[4]

The products resulting from the thermal decomposition of wood can be classified as noncondensable pyroligneous liquor, insoluble tar, and charcoal. The products obtained by laboratory pyrolysis over the range of 250° to 350°C (480° to 610°F) were approximately 27.5 percent water, 10 percent noncondensable gases, 2 percent acids and methanol, 5 percent dissolved tar, and 8 percent settled tar. Over the range of 350° to 450°C (610° to 770°F) the products were 4 percent water, 3 percent noncondensable gases, 2 percent settled tar, and 0.5 percent acids and methanol.[4] The noncondensable gases consisted largely of carbon dioxide and carbon monoxide, with smaller quantities of hydrogen and hydrocarbons.

6.0 AEROSOL FORMATION

Some of the organic materials in wood chip dryer emissions form aerosols upon cooling. These particles form on condensation nuclei, mainly fly ash and other solid particulate, and grow rapidly as the gases are cooled. As these particles exit the stack and are cooled further, they are visible as a blue haze that is characteristic of wood chip dryer emissions. The behavior of small aerosols as they enter the atmosphere is important. Extremely small aerosols are likely to revaporize due to their high vapor pressures. Larger aerosols would be expected to exist for much longer time periods allowing coagulation, agglomeration, and surface chemical oxidation effects to take place.

The size of the smallest aerosol particle possible is given by the equation.[2]

$$d_p = \frac{4\ \sigma\ \bar{v}}{RT\ \ln S}$$

where:

d_p = smallest stable aerosol particle size
σ = surface tension of compound
$\bar{v}$ = molar volume of compound
R = gas law constant
T = absolute temperature
S = degree of supersaturation. This can be taken as the actual vapor pressure of the material in the gas (as a particle) divided by the vapor pressure of the material over a flat surface (bulk liquid).

Particles smaller than d_p will tend to evaporate while particles larger than d_p will tend to grow in a supersaturated gas stream. Figure 1 shows the theoretical minimum particle size produced at different degrees of supersaturation for oleic acid.[2] Rapid cooling of wood chip dryer emissions either by mixing with ambient air or by cooling with water sprays should produce high supersaturations and, thereby, produce submicron aerosol particles. Reference to Figure 2 will show that it is unlikely that any oleic acid particles less than 0.003 μm will form.

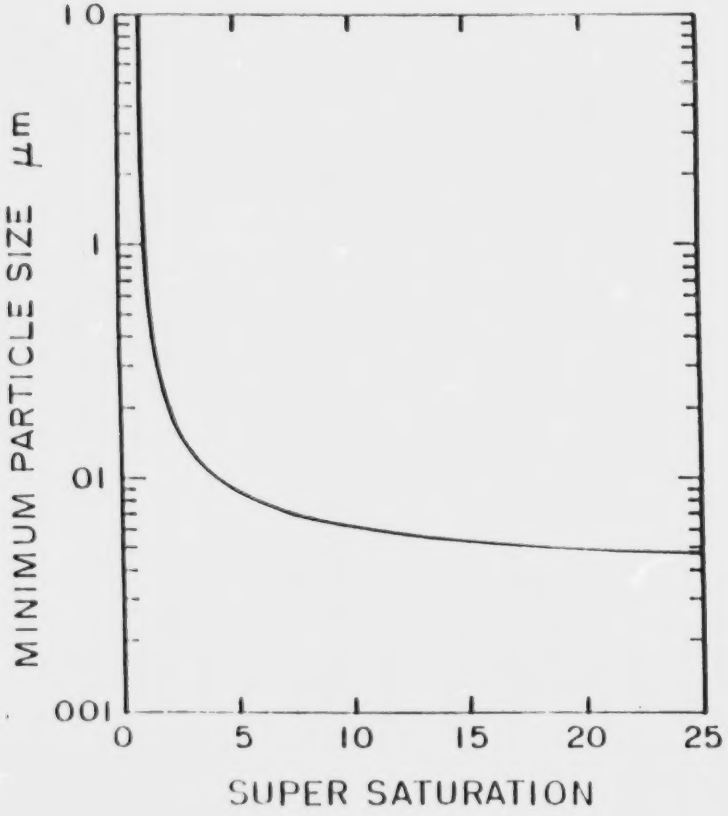


Figure 1. Minimum theoretical particle size formed for oleic acid at various supersaturations.

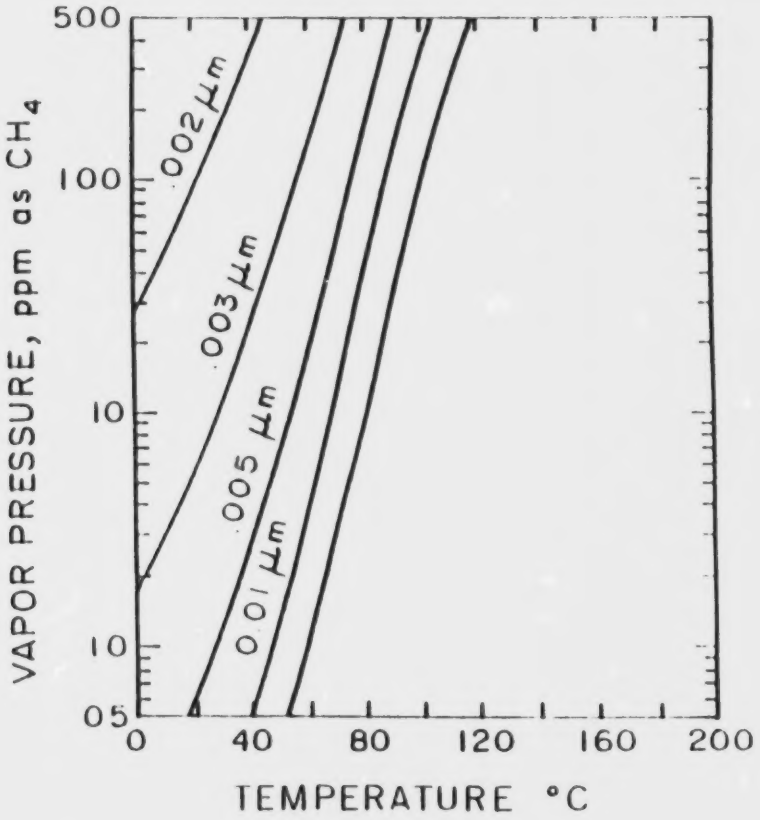


Figure 2. Theoretical vapor pressure of small particles of oleic acid.

Once the wood chip dryer emissions have been cooled and condensation has taken place, the supersaturation of the organics will be reduced because of transfer of material from the gas phase to the liquid phase. Small particles formed under high supersaturation are no longer stable. They will revaporize, and the evaporated organics will tend to recondense on larger particles.[2]

The vapor pressure of a material in a very small diameter particle is much higher than the vapor pressure of that same material over a flat surface. This is known as a the Kelvin effect. A relationship between vapor pressure of a small particle to the vapor pressure over a flat surface is given by:[2]

$$\ln \frac{P_d}{P_s} = \frac{4 \bar{v} \sigma}{d_p RT}$$

where P_d and P_s are the vapor pressures of the material in particle form and over a flat surface (bulk liquid), respectively. Figure 2 shows the Kelvin effect for various particle sizes and temperatures for oleic acid.

No studies have been undertaken to determine the fate of these aerosols in the atmosphere. However, it is known that typically 75 percent of the particulate matter found in uncontrolled wood chip dryer exhaust streams is less than 1 micron in aerodynamic diameter with 65 percent being less than 0.5 microns. More information is needed on wood chip dryer emission particle size distributions from controlled sources to comment on the possibility of revaporization of small aerosols. Furthermore, aerosol behavior in the stack bears no relationship to what might be expected to occur in the atmosphere.

7.0 EMISSION CONTROLS

As discussed in the previous section, wood chip dryer exhaust streams contain dry particulate, products of combustion and pyrolysis, and aerosols formed from the condensation of hydrocarbons volatilized from the wood chips. Study of the particle size distribution indicates that 75 percent of the particulate matter is less than one micron in aerodynamic diameter. The submicron size of this pollutant suggests that wet scrubbers would have to operate in the 60- to 70-inch of water column range to be effective.

Baghouse systems for control of wood chip dryer exhaust streams have been tried and abandoned because of the extreme fire hazards and also because very large air-to-cloth ratios were required due to the 15 percent to 30 percent moisture in the wafer dryer gas stream making the baghouse susceptible to blinding. This makes baghouse systems economically unfeasible and very undependable. No baghouse manufacturer could give a reasonable guarantee that the fire hazard problem or the problems resulting from high moisture could be solved at this time. Resolution of these problems is necessary before baghouse systems offer a long-term dependable solution to controlling particulate matter from a wafer dryer gas stream.

Electrostatic control devices have been demonstrated to be highly efficient at controlling the submicron particulate streams. The two devices currently used to control wood chip dryer effluents are the EFB and the wet ESP. These are the devices that are most likely to be considered in a best available control technology analysis and are discussed in the sections that follow. In addition to controlling emissions using add-on controls, attempts are being made by States and waferboard facilities to reduce the amount of pollutant formed in the dryer. This may be accomplished by reducing dryer inlet temperatures, reducing the load on the dryer, and/or redesigning the dryer flow path.

7.1 ELECTRIFIED FILTER BED

7.1.1 General Description

The EFB fine dust collector is an air pollution control device which serves to remove fine dust and smoke particles from flue gas streams.

Eighty-four units are currently in use for a variety of pollution control applications (see Appendix A). Half are in use to control emissions from waferboard and other composite material dryers.

In the system, the fine dust particles in the exhaust gases are given an electrostatic charge in the corona formed by the ionizer, then are deposited on an electrically polarized filter bed of pea gravel. The pea gravel is removed from the filtration region and cleaned externally in a pneumatic conveyor. The dust removed from the gravel is conveyed to a small bag filter, and the cleaned gravel is returned to the filter. The following sections detail the operation of the various components. A general view of the system and the location of system components are presented in Figure 3.

7.1.1.1 Ionizer. The exhaust gas stream laden with dust enters the system as shown in Figure 4. It turns downward and passes through an annular region formed by two concentric cylinders. Centered in this annulus are four rings spaced vertically 5 inches apart. Sharp-pointed needles protrude from the ring edges. The cylinders are electrically grounded while the rings are held at a high DC negative voltage. Corona discharge from the needle points creates ions, which stream from the needle points toward the adjacent cylinder wall. These ions attach to and, as a result, electrostatically charge the dust particles as they pass.

A set of blowdown nozzles removes dust that accumulates on the needles and tube, impeding the ionization process. Compressed air is supplied to these nozzles periodically on a timed cycle. The ring hanger assembly is rotated slowly (continuously) by a motor drive, cleaning dust from the entire circumference of the wall and needles.

7.1.1.2 Filter Bed. As shown in Figure 5, pea-shaped gravel is held between front and rear louver sets to form the filter bed. The louver structure provides large, nonfouling passages for the gas while retaining gravel by its angle of repose. The louvers are electrically grounded. A cylindrical, expanded metal sheet is suspended between the louver sets and held at a high DC positive voltage. The voltage polarizes the gravel, inducing regions of positive and negative charge on the stones.

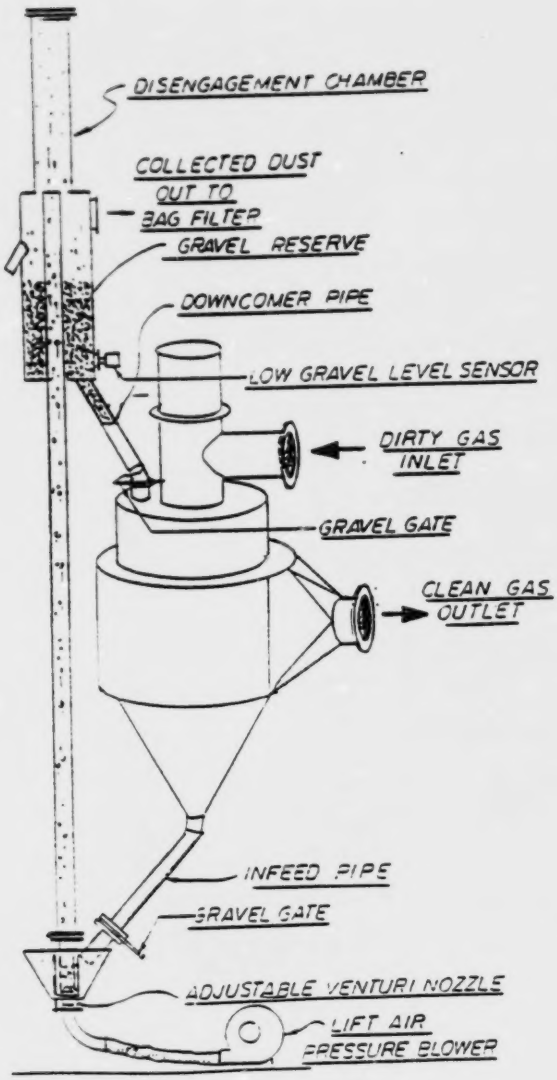


Figure 3. Electrified filter bed system.

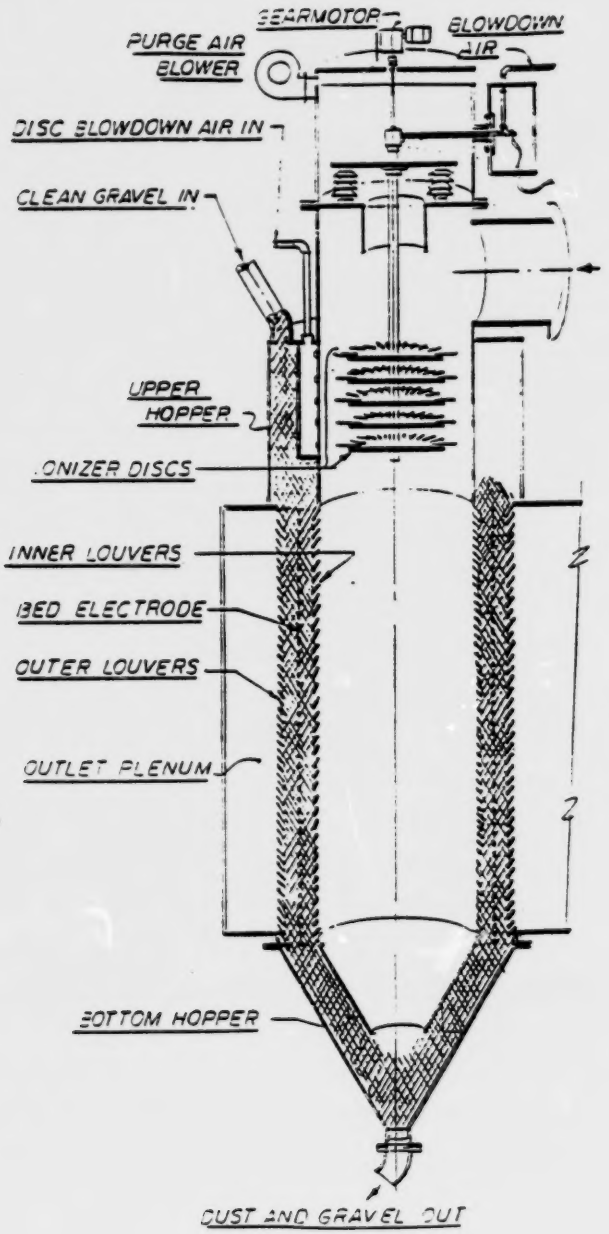


Figure 4. Ionizer and gravel bed assembly.

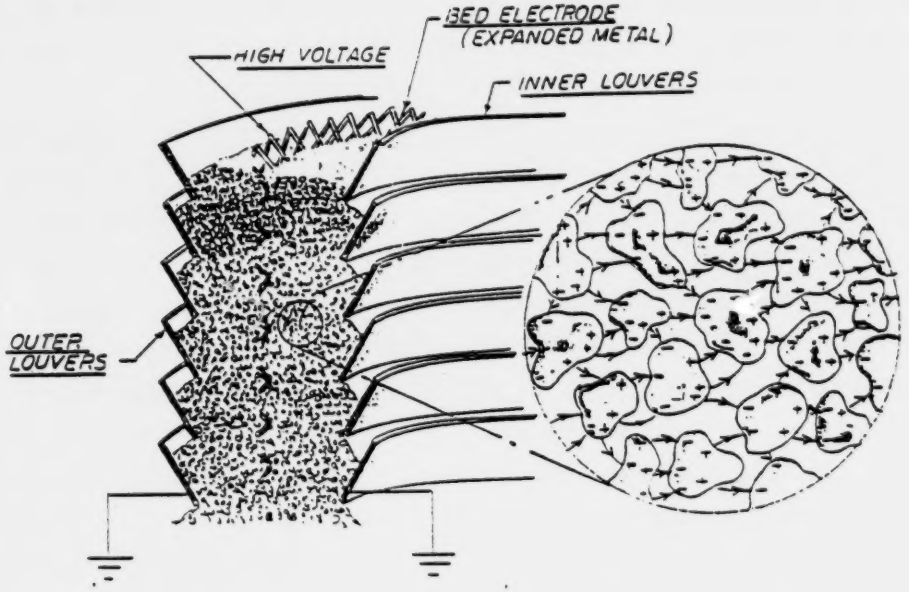


Figure 5. Gravel bed schematic.

After passing through the ionizer, the exhaust gas flows down the chamber inside the inner louvers and then outwardly through the annular filter bed. As it does, the negatively charged dust particles are attracted and attached to the positively charged regions on the gravel. Cleaned gas collects in the outlet plenum and exits the system.

As dust accumulates in the filter bed, it fills the pore spaces and increases the filter's resistance to flow. To maintain constant gas flow pressure drop across the system, the gravel is slowly and continuously removed from the filter bed. The bottom hopper assures uniform gravel flow around the annulus of the filter. Clean gravel is provided to the upper hopper, which is operated in a flooded condition. Gravel feed rate is determined by removal rate from below.

7.1.1.3 Gravel Cleaning/Recirculation. Figures 6 and 7 show the gravel cleaning and recirculation system. The purpose of this system is to clean the gravel and elevate it to the top of the filter bed for reuse. Gravel travels from the bottom hopper to the feeder via the infeed pipe. The infeed pipe, flooded with gravel, acts as an air pressure seal between the feeder and the filter bed. The feeder regulates the gravel recycle rate and carries gravel to the base of the lift line. The lift line blower supplies lift air through a venturi nozzle to the lift line. The venturi creates negative pressure in the feeder, which aspirates dust into the lift line through a slot in the side of the pipe. Gravel rate is set by the nozzle position. Lowering the nozzle opens more slot area and allows more gravel to be pneumatically elevated to the disengagement chamber.

Violent agitation in the lift line, as the gravel is pneumatically conveyed, dislodges dust. The lift line discharges into the disengagement chamber, which decreases air velocity. The cleaned gravel falls into the gravel reserve hopper while the dust is conveyed with the lift air out to the bag filter. The overflow pipe is primarily utilized in loading or unloading of the system with gravel. Under normal operation, the gravel level in the storage pile remains below the overflow level.

Clean gravel returns to the filter as required through the downcomer pipes. The downcomer pipes also act as air pressure seals between the disengagement chamber and the filter.

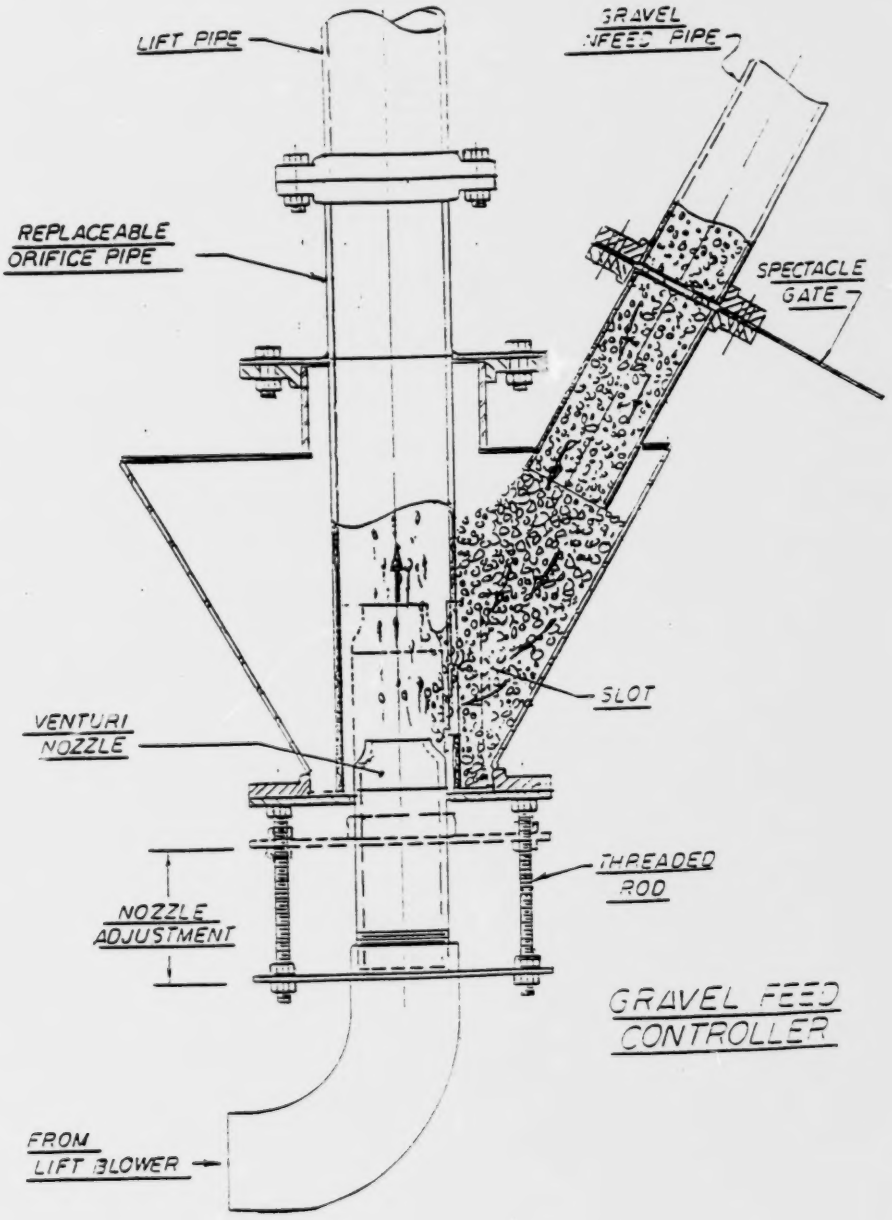


Figure 6. Gravel bed flow controller.

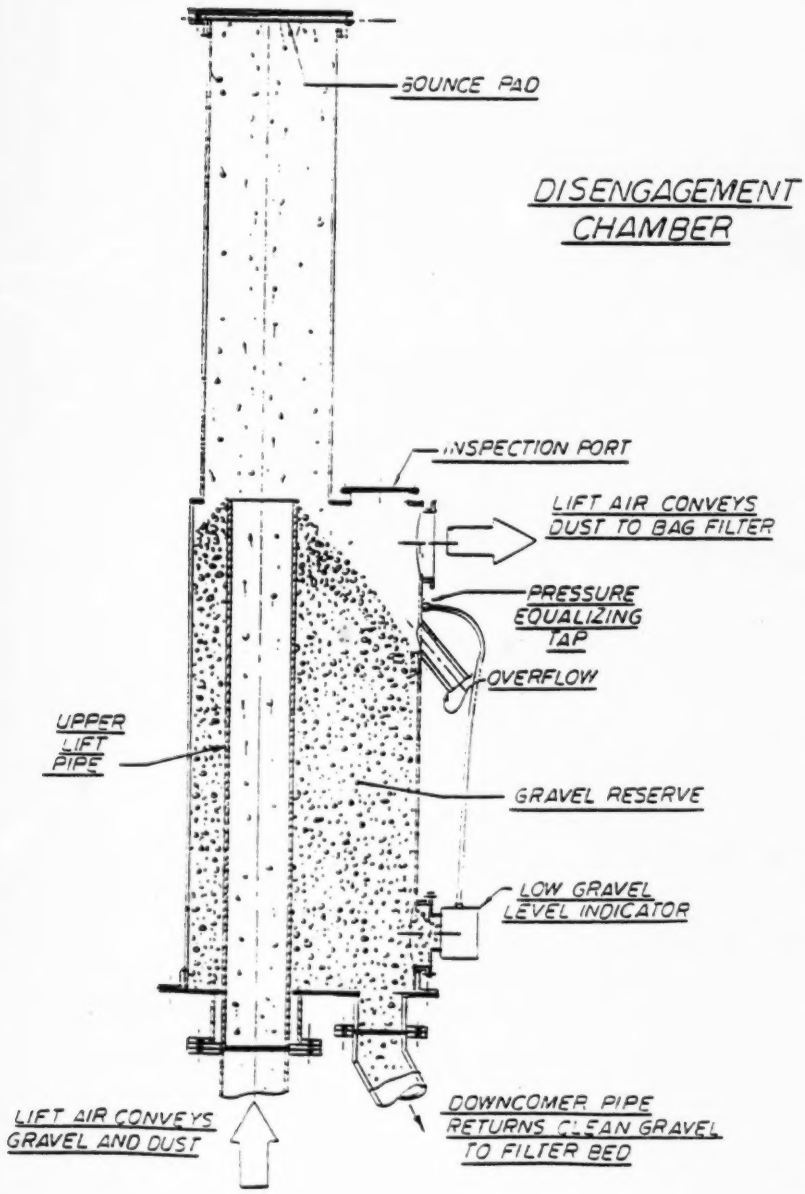


Figure 7. Disengagement chamber.

The dust collector shown in Figure 8 is a conventional pulse jet bag filter. It is equipped with a fan to provide draft from the disengagement chamber to the bag filter. Dust collects on the bags and, at timed intervals, the bags are pulsed with compressed air to dislodge the accumulated dust layer. The agglomerated dust falls to the bag filter bottom hopper where it is discharged through a rotary airlock feeder to the customer's receptable. A hopper vibrator on a timed cycle helps dust flow out of the baghouse hoppers.

7.1.2 Pollutant Removal Efficiencies

With the exception of one test program, all of the testing done to date on EFB systems controlling wood chip dryers has focused on particulate measurements (see Appendix B). Tables 4 and 5 summarize the available information for capture efficiency of particulate matter in an EFB. The data show that average capture efficiencies range from 79 to 94 percent for particulate. Data from a plant desiring to remain anonymous indicates the EFB controls approximately 20 percent of the total hydrocarbon emissions (see Table 5).

7.1.3 Factors Affecting Performance and Suitability

The EFB has been a popular control device in the wood products industry for controlling dryer effluent gases. Because the EFB is a dry type of control, it offers the convenience of producing an effluent stream that requires no further treatment. The unit is also relatively small and does not require a large amount of floor space.

One of the more prevalent problems with the EFB is the sticky hydrocarbon coating that accumulates on the ionizer and gravel during the drying of pine and other high resin content softwood species. According to EFB, Inc., experience has shown that the major factor contributing to the hydrocarbon glaze in their units is condensed moisture. Captured particulate matter laden with hydrocarbon adheres to the gravel. The hydrocarbon dissolves in moisture droplets occasionally formed on the gravel. This produces a glazing of hydrocarbon that is not readily removed by agitation in the disengagement chamber. Over time, the glazing builds up and reduces the efficiency of the unit forcing frequent shutdown and cleaning. According to EFB, Inc., this occurrence can be virtually eliminated by insulating the unit and operating the unit at temperatures

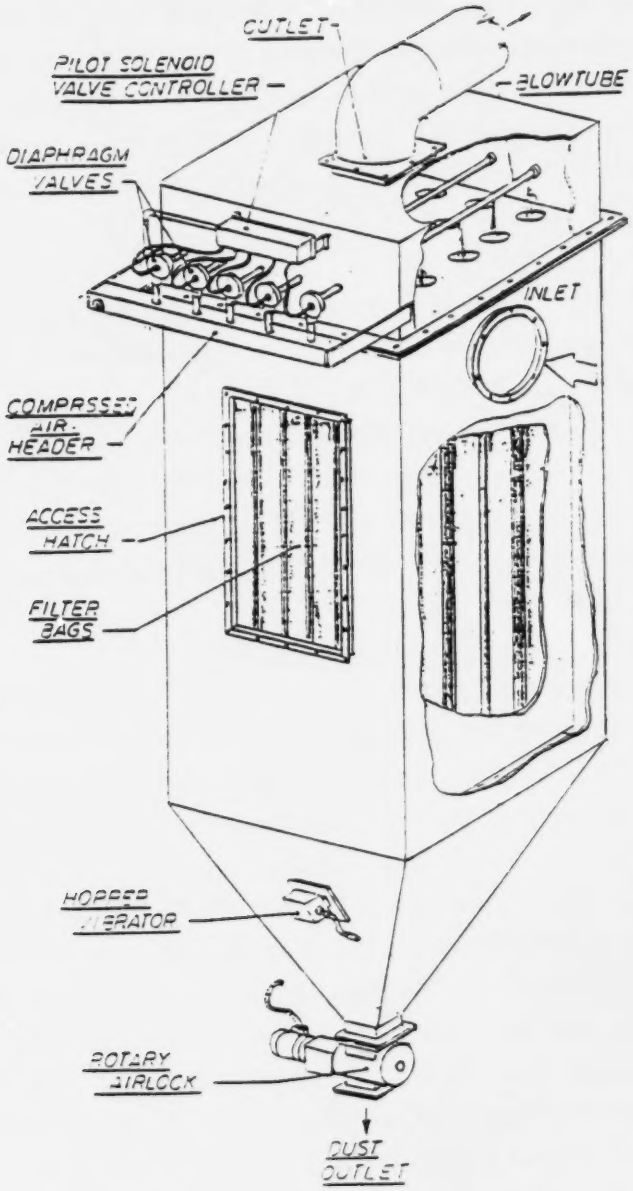


Figure 8. Bag filter.

TABLE 4. EFFICIENCY SUMMARY OF WEYERHAEUSER's EFB IN MONCURE, NORTH CAROLINA, FOR CONTROL OF WOOD PARTICLE DRYER EXHAUST
TEST PERFORMED OCTOBER 20, 1988

Run No.	Inlet particulate, lb/h	Outlet particulate, lb/h	Efficiency, percent
1	21.7	1.52	93.00
2	20.4	1.40	93.14
3	15.4	0.775	94.97
AVERAGE	19.2	1.23	93.70

TABLE 5. EFFICIENCY SUMMARY OF EFB FOR CONTROL OF WOOD PARTICLE DRYER EXHAUST[a]
TEST PERFORMED FEBRUARY 14-17, 1989

Run No.	Particulate			Total hydrocarbon		
	Inlet, lb/h	Outlet, lb/h	Efficiency, percent	Inlet, lb/h	Outlet, lb/h	Efficiency, percent
1	15.4	7.6	51	24.2	21.6	11
3	16.4	1.4	91	33.6	27.4	18
4	10.6	1.3	88	29.4	18.5	37
5	12.0	2.8	77	26.2	19.0	27
10	13.7	1.5	89	20.8	19.8	5
AVERAGE	13.6	2.9	79.2	26.8	21.3	19.6

[a]Plant desires to remain anonymous.

above the dewpoint of the incoming gas stream. A thermal oxidation unit has been used at one plant to burn the resin from the surface of the gravel. It was apparently successful at removing the sticky material but the intense heat caused the gravel to fracture, creating the need for greater amounts of makeup gravel. The gravel used in the EFB is a special basaltic rock mined only in Washington State. A certain number of the rocks will be destroyed in the unit over time and will need to be replaced periodically. The "banging" action in the disengagement chamber is the primary cause of rock destruction.

The EFB has a relatively narrow temperature operating range. The temperature inside the unit must never approach the dew point of the gas stream being treated since condensation of water within the system will result in an electrical short in the gravel bed. As a result, the manufacturers suggest that the unit be operated at 30°F above the dew point temperature. To maintain temperature, some units use a preheater to heat the incoming gas stream. Also, the unit must be preheated before each startup to allow the system components to warm so they do not collect condensation. Units are insulated to minimize heat loss. The need to maintain an elevated temperature in the unit is diametrically opposed to the enhancement of hydrocarbon aerosol formation, which increases the removal efficiency of these compounds.

7.1.4 Costs

Table 6 presents the estimated capital and operating cost for three EFB's for a waferboard plant operating three wood chip dryers and with a projected production rate of 488 tons/day of finished product. These costs were quoted by EFB, Inc., to the Michigan Department of Natural Resources, Air Quality Division, in 1988.[5]

7.2 WET ELECTROSTATIC PRECIPITATORS

7.2.1 General Description

An ESP is a particulate control device that uses electrical forces to move entrained particles out of the flowing gas stream and onto collector plates. Particle collection in an ESP involves three steps: the electrical charging of particles in the gas stream, the collection of the particles on the collection plates or electrodes, and the removal of the collected particulate matter. Wet ESP's are used on effluent gas streams

TABLE 6. EFB COST EVALUATION[9]

I. Installed Capital Costs

Included:

1. Basic units (3)
2. Add booster fan (3)
3. Gravel hoppers (3)
4. Bucket elevators (3)
5. Gravel
6. EFB startup supervision
7. Freight
8. Stacks
9. Ducting, dampers with actuators
10. Platforms and catwalks
11. T.O. piping, insulation
12. MCC's, wiring, CE panel
13. Foundations
14. Installation
15. Crane rental

TOTAL:	$1,050,000

II. Operating Costs (yearly)	Yearly, $
Electrical 300 HP @ 0.04/kw	75,000
Rock replacement	15,000
General maintenance	30,000
Bag replacement	5,000
	125,000

III. Annual Costs	
Capital[a] $1,050,000x0.1627	170,835
Operating	125,000
Total annual costs	295,835

[a]Calculated for 10 year life at 10 percent interest.

containing sticky, condensable hydrocarbon pollutants. These devices have been used extensively in various industrial applications (e.g., aluminum pot lines, carbon anode baking furnaces, and wool fiberglass plants) to control particulate. Five wet ESP's are in service to control wood chip dryer effluents in the waferboard and other wood composite material industries.

Figure 9 presents a diagram of a United-McGill wet ESP. Electric fields are established by applying a direct-current voltage across a pair of electrodes, a discharge electrode, and a collection electrode. Particulate matter and water droplets suspended in the gas stream are electrically charged by passing through the electric field around each discharge electrode (the negatively charged electrode). The negatively charged particles and droplets then migrate toward the positively charged collection electrodes. The particulate matter is separated from the gas stream by retention on the collection electrode. Earlier designs of wet ESP's specified that water sprays be located above the electrodes to create a continuous film of water on the collector plates to wash the collected particulate matter from the plates. The most recent installations have replaced this continuous spray system with an intermittent traveling header system equipped with multiple high-pressure spray nozzles. The high-pressure spray dislodges and removes any remaining organic and particulate buildup from the plates. Use of intermittent high pressure sprays instead of continuous sprays results in a decreased water requirement and reduced voltage degredation in the wet ESP.

7.2.2 Pollutant Removal Efficiencies

At this time, data indicating the efficiency of the wet ESP in removing pollutants from wood chip dryer exhaust streams are limited. To date, only five wet ESP's are on-line to control wood chip dryer exhaust. Georgia-Pacific, which operates three United-McGill wet ESP's, has conducted particulate matter testing on each. These tests, conducted at the inlet and outlet of each precipitator, show an average particulate collection efficiency of from 90.5 to 94.8 percent (see Tables 7 through 9). Georgia-Pacific has also tested for formaldehyde and total gaseous nonmethane organics (TGNMO) at their Woodland, Maine, and Skippers, Virginia, plants. At Woodland, Maine, the wet ESP averaged 70 and 52 percent removal of TGNMO and formaldehyde, respectively (see

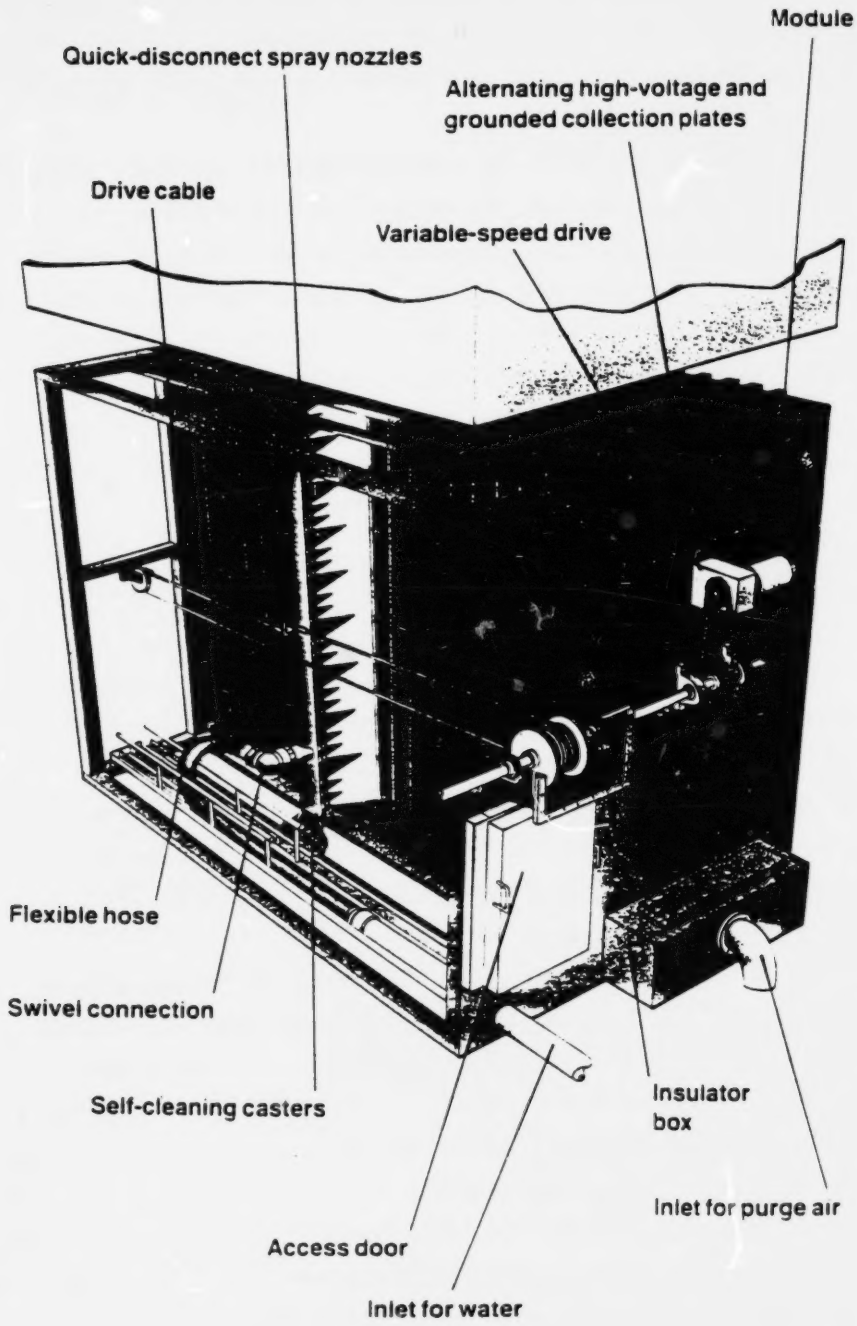


Figure 9. Wet ESP module equipped with traveling spray system.

TABLE 7. EFFICIENCY SUMMARY OF GEORGIA-PACIFIC's WET ESP IN DUDLEY, NORTH CAROLINA, FOR CONTROL OF WOOD CHIP DRYER EXHAUST
TEST PERFORMED SEPTEMBER 1983

Run No.	Inlet particulate, lb/h	Outlet particulate, lb/h	Efficiency, percent
1	81.70	7.712	90.56
2	61.13	7.219	88.19
4	79.29	5.820	92.66
AVERAGE	74.04	6.917	90.47

Test report does not account for Run No. 3.

TABLE 8. EFFICIENCY SUMMARY OF GEORGIA-PACIFIC's WET ESP IN SKIPPERS, VIRGINIA FOR CONTROL OF WOOD CHIP DRYER EXHAUST TEST PERFORMED APRIL 20, 1989

Run No.	TGNMO	Formaldehyde	Particulate
Inlet, lb/h			
1	98.1	9.6	131.5
2	286.2	10.0	46.6
3	177.4	11.4	303.4
AVERAGE	187.2	10.3	160.5
Outlet, lb/h			
1	22.3	8.0	11.7
2	168.5	11.2	14.6
3	84.6	11.5	10.8
AVERAGE	91.8	10.2	12.4
Efficiency, percent			
1	77.2	16.7	91.1
2	41.1	-12.0	68.7
3	52.3	-0.9	96.4
AVERAGE	56.9	1.3	85.4

TABLE 9. EFFICIENCY SUMMARY OF GEORGIA-PACIFIC'S WET ESP IN WOODLAND, MAINE, FOR CONTROL OF WOOD CHIP DRYER EXHAUST TEST PERFORMED OCTOBER 25, 1988

Run No.	TGNMO	Formaldehyde	Dry catch	Dry/wet combination
Inlet, lb/h				
1	83.52	0.1084	80.27	189.81
2	143.21	0.0978	54.36	126.38
3	60.99	0.1294	55.95	142.73
4	--	0.0817	78.28	118.17
AVERAGE	95.91	0.1043	67.22	144.27
Outlet, lb/h				
1	37.99	0.596	3.65	6.45
2	18.77	0.0495	3.70	6.68
3	19.25	0.0490	4.31	7.65
4	--	0.931	5.86	7.97
AVERAGE	25.34	0.0628	4.38	7.19
Efficiency, percent				
1	54.51	45.02	95.46	96.60
2	86.89	49.39	93.20	94.72
3	68.45	62.13	92.30	94.64
4[a]	68.45	(-13.95)[b]	92.52	93.26
AVERAGE	69.95	52.18	93.37	94.81

[a]Plant ran out of chips. Data represents partial run.
[b]Not included in average.

Table 9). At Skippers, Virginia, the wet ESP averaged 57 and 1.3 percent removal of TGNMO and formaldehyde, respectively (see Table 8). Appendix C contains more detailed information on the data collected from the Georgia-Pacific tests.

7.2.3 Factors Affecting Performance and Suitability

There are several performance factors that must be considered when determining the appropriateness of a wet ESP for control of wood chip dryer effluents. Certainly of utmost concern, next to the precipitator's ability to control emisions, is the plant's ability to treat, consume, or discharge the spent spray water and sludge generated by the unit. Spray water used to clean the collection plates is recycled. Each time the spray water is recirculated through the precipitator, more solids become suspended and dissolved in it. It is known that a total solids content of greater than 2 percent will cause spray nozzles in the precipitator to plug. Plugged nozzles must be manually cleaned, resulting in excessive down time of the unit.

Suspended solids are removed relatively easily by flocculation and mechanical removal (i.e., filtration and/or settling). Dissolved solids are not so easily removed. They remain in solution and become more concentrated with each pass through the precipitator. As the total solids content approaches 2 percent, it becomes necessary to remove all of the spent spray water, replacing it with fresh water, or to blow down or remove a portion of the spent spray water on a continuous basis, replacing it with makeup water to reduce the dissolved solids content.

As mentioned earlier, a plant operating a wet ESP must have the means to treat, consume, or discharge the spent spray water and sludge generated by the precipitator. Most waferboard plants are located in rural areas without the services of a local municipal wastewater treatment system to receive their spent spray water. These are plants typically designated as zero discharge facilities and cannot obtain an NPDES permit to release the spent spray water to nearby streams or rivers. As a result, plants using the wet ESP must treat their own spent spray water and/or consume some or all of it internally.

Some plants may have the ability or capacity to consume some or all of their spent spray water internally. Plants that operate boilers or

other wet cell burners that produce steam for the presses, heat for the buildings and hot ponds, or other uses can apply some of the spent spray water to the fuel. Some or all of the remaining spray water may be used as makeup water in the hot ponds and in the debarker for dust control. The amount of spent spray water a plant can consume will vary. Current estimates suggest that approximately 13 gallons per minute of spent spray water will be required as blowdown water to keep the dissolved solids content below 2 percent.

Because wood chip dryer effluents contain sticky organics and dry particulate matter, wet ESP collection plates are particularly succeptable to fouling. If the collection plates are not thoroughly washed in the spray cycle, they can become dry and caked with collected particulate matter. This will reduce the efficiency of the unit and lead to the eventual shutdown and cleaning of the unit. Occasionally, a cake formed on a plate will break loose and become lodged between an ionizing and a collection plate shorting the circuit between the two plates. This also results in reduced efficiency and increased down time.

As discussed in Section 3.0, a major component of the extractable portion of wood are acids. These acids significantly lower the pH of the spray water, which creates a corrosive environment in the precipitator. Caustic is added to the spray water to raise the pH to between 7 and 8. The resulting alkaline pH will react with fats contained in the spray water to produce surfactants (soap) that can cause foaming, thus, antifoaming agents are also added to the spray water. Wood chip dryers that are heated by suspension burners discharge an effluent gas that is less acidic than that heated by a grate-type burner. Suspension burners entrain considerably more fly ash in the dryer effluent than grate-type burners. This fly ash is alkaline and serves to partially neutralize the acidic hydrocarbons exiting the dryer. As a result, suspension burners may reduce the corrosive nature of the effluent and decrease the amount of caustic required to neutralize the spray water.

The most recent wet ESP constructed to control wood chip dryer emissions is at Georgia-Pacific's facility in Woodland, Maine. Gases exiting the dryer enter a prequench to cool and condense (saturate) gases before they enter the precipitator. The prequench is essentially a low-

energy scrubber that sprays water into the incoming gas stream. The gas that exits the prequench is saturated (i.e., multicomponent hydrocarbons here approached their vapor-liquid equilibrium), and, thus, further cooling in the precipitator will condense and capture more of the condensable hydrocarbon, mainly the sticky resins. Because the wet ESP cannot collect by electrostatic removal any material that will not condense, the prequench chamber increases removal efficiency by lowering the gas temperature, thus, saturating the stream and maximizing the condensation of hydrocarbon for removal.

The wet ESP operates well under a variety of conditions. The operating window is usually wide enough that process upsets in the dryers and increased production and airflows are not a problem. One properly designed and sized unit should have the capacity to serve the pollution control needs of a multidryer plant. To date no facility has required or installed multiple wet ESP's for the control of wood chip dryer exhaust streams. However, wet ESP's are large and require substantial space.

7.2.4 Costs

Table 10 presents the estimated capital and operating cost for a wet ESP installed in a waferboard plant operating three wood chip dryers and with a projected production rate of 488 tons/day of finished product. These estimates were made for Louisiana-Pacific's plant in Sagola, Michigan. These costs were reviewed by the Michigan Air Quality Division, Louisiana-Pacific, and United McGill in April of 1988, and all parties agreed that the costs appeared to be accurate.[5]

TABLE 10. CAPITAL AND OPERATING COST OF WET ESP[3]

I.	**Installed Capital Cost**	
	Base system installed	$1,733,400
	Fan with motor, starter, rigging, & wiring	NA[a]
	Foundation, floor, aprons, and roads	40,000
	40 gal/min water supply (well)[b]	35,000
	GEP stack, foundation, and platform	70,000
	Enclosure heating and heat tracing	2,000
	Power source (180 amp, 3 phase)[b]	5,000
	Bleed off water and sludge handling	10,700
	Water clarification system	NA[a]
	Total installed price	1,896,100
II.	**Operating costs**	**$/year**
	A. Electrical demand	
	1. Precipitator	
	a. Transformer/rectifiers (14.5 kw)	5,080
	b. Purge air (8.5 kw)	2,978
	c. Controls (0.8)	280
	d. Chamber lights (1.0 kw)	350
	e. Traveling header (0.1 kw x 3)	105
	2. Water treatment and circulation system	
	a. Controls (0.4 kw)	140
	b. Pumps (39.2 kw)	13,736
	c. Sludge dewater (1.5 kw)	526
	d. Clarifier (1.5 kw)	526
	Total kw (cost $0.04/kw)	23,721
	B. Water supply (15,000 gal/day @ $0.02/100 gal)	1,905
	C. Operation and maintenance (assumed labor costs of $20/hour)	
	1. Full-time operator/supervisor (40 hours/week)	41,600
	2. Plate and nozzle cleaning (2 people, 1 day every other week, 416 hours/year)	8,320
	3. Weekend operation unscheduled repairs, etc. (16 hours/week)	16,640
	4. Replacement parts	10,000
		76,560
	D. Chemical consumption	
	1. Polymer (50 lb/day)	37,200
	2. Caustic soda (110 gal/day)	55,956
		93,156
	Total annual operating costs	195,342
III.	**Annual Costs**	
	Capital (1,896,100)(0.1175)[c]	222,792
	Operating	195,342
	Total annual costs	$418,134

[a] Included.
[b] Figures provided by Louisiana-Pacific.
[c] Calculated for 20 year life at 10 percent interest.

8.0 LOW/REDUCED TEMPERATURE DRYING

Dryer configurations and operation vary from plant to plant. The typical dryer, however, accomplishes a tremendous amount of work in a relatively short time, in a relatively small space, and within rather demanding limits. At the same time, unacceptable emissions can be generated that can be characterized as solid particulate matter, which is normally invisible, and liquid particulate (aerosol) or blue haze condensable hydrocarbons, which are normally very visible. These emissions are to a large degree a function of the wood species being dried. However, dryer temperatures, dryer loading rates and dryer design also affect pollutant emission rates.

8.1 DRYER TEMPERATURE VERSUS EMISSIONS

Most dryers in operation utilize high volumes of air to convey material of varied size through one or more passes within the dryer and then discharge the material pneumatically to a cyclone. The high material flow rate through a cyclone handling a gas stream with a large proportion of smaller sized material results in emissions even when the cyclone is performing at a high removal efficiency. The blue haze condensable hydrocarbons have been observed being emitted only from dryers removing less than 10 percent of moisture and with operating temperature of greater than 700°F (371°C).[6]

Table 11 presents data from diagnostic testing done on a particle board dryer in Rapid City, South Dakota.[7] Temperature increases throughout the range of 550°F to 950°F (310°C to 560°C) showed that small increases in the inlet temperatures produced relatively large increases in the particulate mass rate. The study also showed that moisture content, once thought to be a key variable in the entire opacity and particulate equation, proved within a large range to be insignificant.

The report suggested that low temperature drying could be accomplished through the addition of predryers for the green materials. The additional dryers would alleviate the excessive loading of the existing dryers and would allow them to operate at low temperatures while achieving the desired moisture content in the product. In addition to the production flexibility of having additional dryers, operating and

TABLE 11. INCREASE OF PARTICULATE MASS RATE WITH INCREASING INLET TEMPERATURE

Target inlet temp.,	Particulate mass rate, lb/h	Increase in mass rate, percent	Cumulative increase in mass rate, percent
550	3.77	NA[a]	a
650	5.95	58	58
750	9.02	52	139
850	12.66	40	236
950	18.47	46	390

[a]NA = Not applicable.

maintenance techniques for dryers and their associated equipment are usually well-known to plant personnel.

8.2 DRYER LOADING VERSUS EMISSIONS

Another critical cause of blue haze is overloading a dryer by attempting to remove too much moisture within a given time. Overloading results in the introduction of green material to a high-temperature flame or gas stream causing a thermal shock that results in rapid and excessive volatilizing of hydrocarbons that condense upon release to ambient air, causing the characteristic blue haze.

In conventional three-pass dryers, the velocity of the air slows through the second and third passes, allowing larger particles to settle out and smaller particles to pass through; however, this is not the case at high material flow rates. Larger settled particles will interrupt the flow of the smaller, faster moving particles with the result being that all particles are traveling at a rate determined only by the forward velocity of the larger particles. When smaller particles are held at these slower velocities in the second and third passes for a prolonged period of time, volatilization of their surfaces occurs, which results in the formation of hydrocarbon and carbon monoxide emissions. Should plugging occur in the second or third passes due to the material dropping out of suspension, elevation of particle surface temperatures to their flash points will result in combustion.

8.3 PRODUCTIZATION 3PHV DRYER

The conventional three-pass dryer is a rotating cylindrical drum that consists of three, concentric, interlocked cylinders. Hot gases enter the innermost cylinder with the wet wood chips and progress through the intermediate and then the outer drum shells in a serpentine flow path while pneumatically conveying the wood chips through the dryer.

The 3PHV rotary dryer, shown in Figure 10, like the conventional three-pass dryer, is a rotating cylindrical drum consisting of three, concentric, interlocking cylinders. In the 3PHV dryer, hot gases enter the outermost cylinder with the wood chips and progress through the intermediate and then the inner drum shells in a serpentine flow path. This flow path direction is the opposite of that in the conventional three-pass dryer (see Figure 11). The reason the 3PHV dryer should reduce emissions is described below.

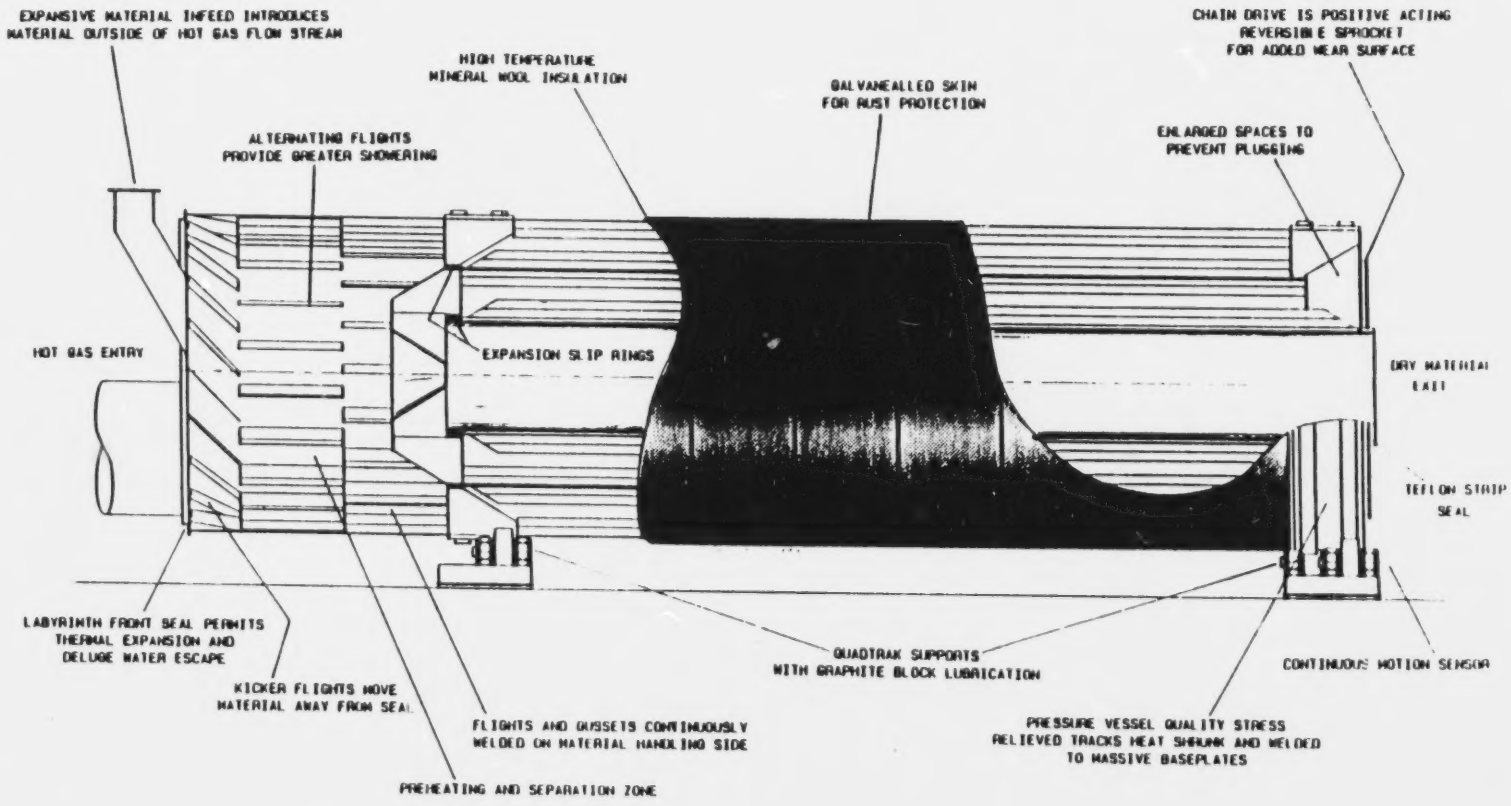
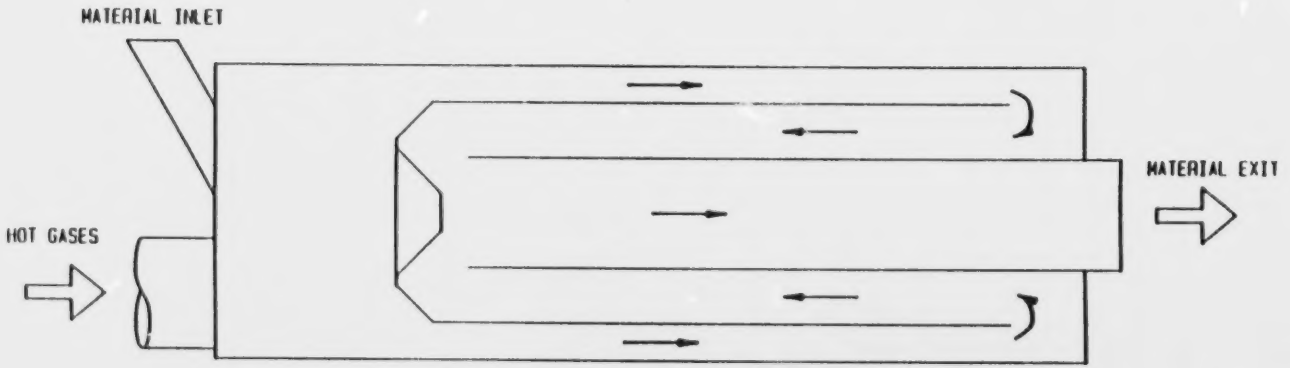

EXPANSIVE MATERIAL INFEED INTRODUCES MATERIAL OUTSIDE OF HOT GAS FLOW STREAM
HIGH TEMPERATURE MINERAL WOOL INSULATION
GALVANEALLED SKIN FOR RUST PROTECTION
CHAIN DRIVE IS POSITIVE ACTING REVERSIBLE SPROCKET FOR ADDED WEAR SURFACE
ALTERNATING FLIGHTS PROVIDE GREATER SHOWERING
ENLARGED SPACES TO PREVENT PLUGGING
HOT GAS ENTRY
EXPANSION SLIP RINGS
DRY MATERIAL EXIT
TEFLON STRIP SEAL
LABYRINTH FRONT SEAL PERMITS THERMAL EXPANSION AND DELUGE WATER ESCAPE
KICKER FLIGHTS MOVE MATERIAL AWAY FROM SEAL
FLIGHTS AND GUSSETS CONTINUOUSLY WELDED ON MATERIAL HANDLING SIDE
QUADTRAK SUPPORTS WITH GRAPHITE BLOCK LUBRICATION
CONTINUOUS MOTION SENSOR
PRESSURE VESSEL QUALITY STRESS RELIEVED TRACKS HEAT SHRUNK AND WELDED TO MASSIVE BASEPLATES
PREHEATING AND SEPARATION ZONE
3PHV ROTARY DRUM DRYER
PRODUCTIZATION, INC.
Independence, Kansas 67301
U.S. PATENT NO: 4720170 (7/88-BROCHURE)

Figure 10. Productization 3PHV rotary drum dryer.



PRODUCTIZATION, INC. 3PHV DRUM DRYER

CONVENTIONAL TRIPLE PASS DRUM DRYER

FLOW COMPARISON
PRODUCTIZATION, INC.
Independence, Kansas 67301

Figure 11. Flow comparison of conventional triple pass dryer and 3PHV drum dryer.

A determinant in establishing a saltation (conveying) velocity for a particle is the relationship between the density of the particle to the density of the supporting gases. As wet particles dry, their density decreases, and as gases cool (due to the transfer of heat), their density increases. When the density of the particle decreases sufficiently due to its drying, and the density of the cooling gases increases sufficiently, the aforementioned relationship determining an individual particle's saltation velocity dictates that the saltation velocity will decrease. If the gas velocities are greater than the particle's saltation velocity, the particle will be pneumatically conveyed. Gas velocities in the primary and secondary passes of the 3PHV are not capable of supporting (pneumatically conveying) any but the least dense (dryest) particles. The denser (still moisture laden) particles will undergo a showering action in these passes while being propelled not at conveying velocities, but at velocities determined by a combination of drag and gravity forces.

Because small particles have a higher surface area in proportion to their mass, moisture is more rapidly evaporated from their surfaces. Also, heat and, therefore temperature gradients traverse to the center of smaller particles more rapidly than larger ones. As the moisture is evaporated from the particle, the particle density is reduced. Once the saltation velocity of the particle is reduced below the prevailing gas velocity, the particle is picked up in the gas stream and conveyed through the remaining drums.

Larger particles are retained in the outer drum where they undergo showering action and are subjected to turbulent airflow. Once the moisture of these larger particles is reduced to the desired moisture content, particle densities are likewise reduced, which allows them to reach their own saltation velocities. Larger particles will reach their respective saltation velocities in either the outer (first pass) or intermediate (second pass) drum depending upon their size, weight, and moisture content.

In the first pass, the 3PHV dryer allows smaller, dried particles to pass through the slower moving mass of larger, wetter particles in an area bounded by the outer and intermediate drum cylinders, which is much larger than the area of the inner drum of conventional triple pass dryers. As

the larger particles are dried, they will "catch up" with the smaller faster moving particles in an area bounded by the intermediate (second pass) drum cylinder. Here, airflow velocities become high enough to convey the entire mass of particles out of the drying portion of the drum and into the inner (third pass) drum cylinder where they will be conveyed out of the dryer.

In summary, as particles dry, they approach their saltation velocity. As they reach saltation velocity, it is important to provide a gas velocity sufficient to pick up the particle and pneumatically convey it out of the drying environment. This action prevents the product from reaching temperatures in excess of the wet bulb temperature, thus reducing carbon monoxide and hydrocarbon emissions associated with pyrolysis and combustion of the wood chips. Appendix D contains more detailed information on the productization 3PHV dryer.

9.0 PRESS VENTS

Emissions from the press vents result as compounds in the resin used to bind the chips evaporate when heated. These emissions usually exit through exhaust fans mounted on the roof above the presses. Georgia Pacific's plant in Lebanon, Oregon, is the only plant in the country attempting to control emissions from the press vents. A spray chamber containing 80 spray nozzles continuously sprays the exiting press vent gases with water to cool, condense, and adsorb some of the hydrocarbons. The spray chamber, installed in 1972, has never been tested so no information is available regarding pollutant removal efficiencies.

The type of resin used and, thus, the compounds present in its formulation vary depending upon the type of panel being manufactured. Urea/formaldehyde (UF) resins are primarily used in the production of particle board and medium density fiberboard. These panels typically contain 8 to 9 percent (w/w) resin. The UF resin is used in applications where the final product will not be subject to weathering. Phenol/formaldehyde (PF) resins are used in the production of structural particle board, waferboard (WB), and oriented standardboard (OSB). Structural particle board contains approximately 6 percent (w/w) resin, and WB and OSB contain approximately 2 percent (w/w) resin. The PF resins are more resistant to moisture than UF resins.

In an effort to eliminate the potential for formaldehyde emissions, MDI resins have been used by some manufacturers. The MDI resins produce a higher strength panel than the UF or PF resins. Therefore, manufacturers are able to use less MDI resin to meet the industry's product standards. However, MDI resins are much more expensive than UF or PF resins, and panels produced with MDI resins tend to stick to the presses. Two approaches have been used to prevent the panels from sticking. One is to spray the presses lightly with an antisticking agent between press cycles. Another approach is to use UF or PF resins to bind the material on the two outer surfaces of the panel. The core of the panel is bound with the MDI resin. This reduces the amount of formaldehyde available to volatilize and the panel retains the structural strength provided by the MDI resin.

In a recent study, three factors were identified that affected formaldehyde emissions from press vents: (a) the excess formaldehyde content of the resin, (b) the amount of resin used, and (c) the press temperature.[8] Excess formaldehyde is the amount of formaldehyde in the resin in excess of the amount required for stoichiometric reaction with the urea or phenol in the resin. The emission rates have been shown to increase in proportion to the increase in the free formaldehyde content of the resin. The excess or free formaldehyde contents of resins are often held proprietary by resin manufacturers. The study showed that where such information was available, the data indicated that 5 to 15 percent of the excess formaldehyde in the panelboard was emitted during the pressing and board cooling operations.[8]

New resin formulations use constituents other than urea to react with the formaldehyde. Because of this, the stoichiometric ratio of formaldehyde to urea cannot be used to predict the formaldehyde emission rate.

A better method to compare resins for their potential to emit formaldehyde during particleboard manufacture would be to use the excess formaldehyde content of the resin calculated on the basis of the amount of formaldehyde in excess of the amount needed to react stoichiometrically with the urea and other reactive constituents in the resins. However, resin manufactures will not divulge sufficient information about their resins to allow these calculations to be made.

The study also showed that the emission rate of formaldehyde increased in proportion to the amount of resin used in the panelboard and the press temperature. The formaldehyde emission factors ranged between 0.30 and 0.75 lb/thousand square feet of product using UF resin.[8]

The results of the study show that the formaldehyde emissions from particleboard press vents are related to the amount of excess formaldehyde in the unpressed boards loaded into the press. It would appear that formaldehyde emission rates could be reduced by using less excess formaldehyde in the resin. The industry has already decreased the amount of excess formaldehyde in resins in order to reduce the emissions of formaldehyde from the finished product into the living or work space. This reduction of excess formaldehyde in the resin also resulted in longer press times and, hence, reduced production rates.

Two recent tests for VOC emissions at Louisiana Pacific plants shed some light on the level of VOC emissions that might be expected from press vents.

TABLE 12. VOC EMISSION FACTORS FOR PRESS VENTS[10]

Plant	Interpoll Labs Report No.	Resin	VOC emission factor, lb VOC/ton product
Hayward, Wis.	7-2405	100 percent MDI	0.36
Sagola, Mich.	8-2552	50 percent liquid PF for surface and 50 percent MDI for the core	0.56

The above results can be used to estimate VOC emissions for 100 percent PF resin, since data collected by Interpoll Labs has shown that the MDI is not volatilized. This being the case, the 100 percent MDI test VOC emission factor is indicative of the VOC's emitted from the wood itself (E_w) and the 50:50 test correspond to the VOC's emitted from the wood and from the PF resin in the surface (E_s). The general relationship is shown below:

$$E_t = E_w+E_c+E_s+E_{MDI}$$

where:

E_t = total VOC emission factor;

E_w = VOC emission factor due to VOC's emitted from the wood;

E_c = VOC emission factor due to VOC's emitted from PF resin in the core;

E_s = VOC emission factor due to VOC's emitted from PF resin on the surface; and

E_{MDI} = VOC emission factor due to volatilization of MDI = 0.

In the case where 100 percent MDI was used:

$$E_c = E_s = E_{MDI} = 0$$

and thus:

$$0.36 = E_w+0+0+0$$

$$E_w = 0.36 \text{ lb VOC/ton product}$$

This is equivalent to saying that the use of 100 percent MDI allows estimation of the base VOC emission factor for the wood in the board. A plant using 50 percent MDI (in the core) and 50 percent P/F resin (on the surface) is represented in terms of the general equation as follows:

$$0.56 = E_w+E_c+E_s$$

Since $E_w = 0.36$ and $E_c = 0$ because MDI was used in the core, then:

$$0.56 = 0.36+0+E_s$$

$$E_s = 0.20 \text{ lb VOC/ton product}$$

Now if it may be assumed that $E_c \leq E_s$ (which is a very safe assumption, since loss of PF from the core is much less likely than loss of PF from the surface of the waferboard, then the total VOC emission factor where 100 percent PF is used may be calculated as follows:

$$E_t = E_w+E_c+E_s$$

where

$E_w = 0.36$

$E_s = 0.20$

$E_c \leq 0.20$, then

$E_t = 0.36+0.20+\leq 0.20$

$E_t \leq 0.76$ lb VOC/ton product

This analysis suggests that use of MDI resins instead of PF resins would result in a 50 percent reduction in VOC emissions. Other estimates (see Appendix E) suggest that changing from PF resins to MDI resin will result in a 90 percent decrease in formaldehyde emissions from the press vents.

10.0 REFERENCES

1. Hillis, W. E. Wood Extractives and Their Significance to the Pulp and Paper Industries. Academic Press, New York. 1962.

2. A Study of Organic Compound Emissions from Vendor Dryers and Means for Their Control. NCASI Technical Bulletin No. 405. August 1983.

3. A Survey of Emissions from Dryer Exhausts in the Wood Panelboard Industry, NCASI Technical Bulletin No. 504. September 1986.

4. Browning, B. L. The Chemistry of Wood, Interscience Publishers, New York. 1963.

5. Letter. Wardell, L. L., Michigan DNR to Dimmick, F., CTC. June 2, 1988.

6. Maloney, T. M. Modern Particleboard and Dry-Process Fiberboard Manufacturing. Miller Freeman Publications, Inc. San Francisco, California. 1977.

7. Kandaras, C. "Diagnostic Tests Result in Low Temperature Drying for Particulate Emission Controls." Proceedings of the Twenty-Fifth Washington State University International Particleboard/Composite Materials Symposium. March 1987.

8. A Survey of Formaldehyde and Total Gaseous Nonmethane Organic Compound Emissions from Particleboard Press Vents. NCASI Technical Bulletin No. 483. June 1986.

9. Formaldehyde, Phenol, and Total Gaseous Nonmethane Organic Compound Emissions from Flakeboard and Oriented-Strand Board Press Vents. NCASI Technical Bulletin No. 503. September 1986.

10. Friedman, J. N., Lonnes, P. PSD Applicability Analysis of the proposed plant expansion of the OSB plant in Bemidji, Minnesota. Interpoll Laboratories, December 4, 1988.

APPENDIX A.

EFB AND ESP USER LIST

EFB USER LIST

Company	Location	Application	Flow,acfm	Start Up
Louisiana-Pacific	Houlton, ME	OSB Dryer	50,000	June 1989
Louisiana-Pacific	Houlton, ME	OSB Dryer	50,000	June 1989
Louisiana-Pacific	Hayward, WI	Wood Fired Boiler	40,000	May 1989
Louisiana-Pacific	Hayward, WI	Wood Fired Boiler	32,000	May 1989
Allegheny Particleboard	Mt. Jewett, PA	Particleboard Dryer	77,000	Nov 1989
Allegheny Particleboard	Mt. Jewett, PA	Particleboard Dryer	77,000	Nov 1989
Allegheny Particleboard	Mt. Jewett, PA	Particleboard Dryer	77,000	Nov 1989
Kronospan	Sandebeck, D	Chipboard Dryer	130,000	Apr 1989
Mason Chamberlain	Picayune, MS	Steel and Alum. Forging	120,000	May 1989
Louisiana-Pacific	Sand Point, ID	Wood Fired Boiler	70,000	Feb 1989
Packwood-Hurst	Packwood, WA	Wood Fired Boiler	30,000	Jan 1989
VA Hospital	Seattle, WA	Hospital Incinerator	10,000	Jan 1989
Schenck-Weyerhaeuser	Elkin, N.C.	OSB Dryer	60,000	Eng Contr
Schenck-Weyerhaeuser	Elkin, N.C.	OSB Dryer	60,000	Eng Contr
Sverdrup	Nashville, TN	Wood Fired Boiler	70,000	May 1988
Weyerhauser Co.	Springfield, OR	Particleboard Dryer	50,000	Jan 1989
Weyerhauser Co.	Springfield, OR	Particleboard Dryer	50,000	Jan 1989
Northern States Power	Ashland, WI	Wood/Coal Fired Boiler	160,000	Sept 1988
Northern States Power	Ashland, WI	Wood/Coal Fired Boiler	160,000	Sept 1988
Willamette Ind.	Foster, OR	Plywood Veneer Dryer	40,000	June 1988
Louisiana-Pacific	Hayward, WI	OSB Dryer	50,000	Mar 1988
Louisiana-Pacific	Hayward, WI	OSB Dryer	50,000	Mar 1988
U.S. Plywood	Gaylord, MI	Particleboard Dryer	70,000	Apr 1988
Louisiana-Pacific	Hayward, WI	OSB Dryer	50,000	Feb 1988
Louisiana-Pacific	Hayward, WI	OSB Dryer	50,000	Feb 1988
Weyerhaeuser Co.	Grayling, MI	OSB Dryer	50,000	Sept 1987
Weyerhaeuser Co.	Grayling, MI	OSB Dryer	50,000	Sept 1987
Weyerhaeuser Co.	Grayling, MI	OSB Dryer	50,000	Sept 1987
Weyerhaeuser Co.	Grayling, MI	OSB Dryer	50,000	Sept 1987
Badger Foundry	Winona, WI	Grey Iron Foundry	13,000	Aug 1987
Louisiana-Pacific	Sagola, MI	Wood Fired Boiler	50,000	Jan 1988
Potlatch	Bemidji, MN	OSB Dryer	30,000	Aug 1987
Potlatch	Bemidji, MN	OSB Dryer	30,000	Aug 1987
Potlatch	Bemidji, MN	OSB Dryer	30,000	Aug 1987

EFB USER LIST

Company	Location	Application	Flow,acfm	Start Up
Potlatch	Bemidji, MN	OSB Dryer	30,000	Aug 1987
Boise-Cascade	Lagrande, OR	Particleboard Dryer	35,000	July 1987
Boise-Cascade	Lagrande, OR	Particleboard Dryer	35,000	July 1987
Louisana-Pacific	Sagola, MI	OSB Dryer	60,000	July 1987
Louisana-Pacific	Sagola, MI	OSB Dryer	60,000	July 1987
Louisana-Pacific	Sagola, MI	OSB Dryer	60,000	July 1987
Northern States Power	French Island, WI	RDF/Wood Fired Boiler	120,000	Sept 1987
Seaman Paper Co.	Baldwinville, MA	Wood Fired Boiler	40,000	Apr 1987
Weyerhaeuser, Co.	Moncure, NC	Particleboard Dryer	70,000	Mar 1987
BP Canada	Montreal, PQ	Asphalt Saturator	50,000	Mar 1987
Weyerhaeuser, Co.	Moncure, NC	Particleboard Dryer	70,000	Mar 1987
First Aroostook	Sydney, NS	MSW Incinerator	70,000	Dec 1986
Pinetree Power	Bethlehem, NH	Wood Fired Boiler	120,000	Dec 1986
Potlatch	Cook, MN	OSB Dryer	30,000	Dec 1986
Potlatch	Cook, MN	OSB Dryer	30,000	Dec 1986
Northwood Panelboard	Bemidji, MN	OSB Dryer	50,000	Dec 1986
International Paper	Nacogdoches, TX	Wood Fired Boiler	35,000	Nov 1986
Potlatch	Cook, MN	OSB Dryer	30,000	Nov 1986
Potlatch	Cook, MN	OSB Dryer	30,000	Nov 1986
J.M. Huber	Easton, ME	Wood Fired Boiler	50,000	July 1986
Northwood Panelboard	Bemidji, MN	OSB Dryer	50,000	Sept 1986
Louisiana-Pacific	Two Harbors, MN	OSB Dryer	50,000	Apr 1986
Louisiana-Pacific	Chilco, ID	OSB Dryer	50,000	Mar 1986
Louisiana-Pacific	Dungannon, VA	OSB Dryer	50,000	Feb 1986
Louisiana-Pacific	Kremmling, CO	OSB Dryer	50,000	Oct 1985
Louisiana-Pacific	Montrose, CO	OSB Dryer	50,000	Sept 1985
Vanguard Products	Danbury, CT	Silicon Rubber Curing	5,000	Nov 1985
Proctor & Gamble	Greenbay, WI	Wood Fired Boiler	75,000	Dec 1985
Northwood Panelboard	Bemidji, MN	Wood Fired Boiler	25,000	Oct 1985
DuPont	Washington, WV	Plastic Extrusion	5,000	Sept 1985
Northwood Panelboard	Bemidji, MN	Wood Fired Boiler	27,000	Aug 1985
G2S Constructors	Lewiston, ME	Wood Fired Boiler	80,000	May 1985
Kelley Co.	L.A., CA	MSW Incinerator	8,000	Apr 1985
Chamberlain Mfg. Co.	New Bedford, MA	Steel Forging	200,000	May 1985

EFB USER LIST

Company	Location	Application	Flow,acfm	Start Up
General Electric	Ballston Spa, NY	PFB Coal Combustor	1,000	Sept 1984
Bio-Energy	Concord, NH	Wood Fired Boiler	100,000	June 1984
Alcoa	Cleveland, OH	Aluminum Forging	100,000	Sept 1983
Domtar	Lachine, QE	Asphalt Saturator	20,000	Aug 1983
CHR Industries	New Haven, CT	Silicone Rubber Curing	8,000	June 1983
Coatings Engineering	Sudbury, MA	PVC Curing Oven	8,000	Dec 1982
Voltek	Lawrence, MA	Polyethylene Curing	16,000	July 1982
GM Co.-Chevrolet Div.	Livonia, MI	Metal Polishing	20,000	June 1985
3M Co.-Chemolite Div.	St. Paul, MN	Glass Bubble Former	20,000	Dec 1981
Shaw Pipe	Vancouver, B.C.	Coal Tar Pipe Coating	20,000	Nov 1981
Bay State Smelting	Somerville, MA	Brass Smelting	20,000	Nov 1981
Airco Speer	St. Mary's, PA	Carbon Electrode Mfg.	8,000	Dec 1980
Schlage Lock	Denver, CO	Brass Foundry	8,000	Nov 1980
Canadian Gypsum	Winnipeg, MB	Asphalt Saturator	20,000	Sept 1980
Domtar	Vancouver, B.C.	Asphalt Saturator	20,000	Mar 1980
Globe Roofing	Vancouver,B.C.	Asphalt Saturator	20,000	Oct 1979
Canadian Johns-Manville	Toronto, ON	Fiberglass Curing	30,000	Apr 1979
ERCO	Cambridge, MA	FB Coal Combustor	20,000	Aug 1981
Quality Aluminum	Milwaukee, WI	Aluminum Foundry	20,000	May 1981
Rumford Nat'l Graphics	Concord, NH	Lithography Press	18,000	May 1981

INSTALLATION LIST BY APPLICATION

in chronological order by purchase date

CHIP DRYERS (WEP)

No.	Order Date/ Startup Date	Customer/Location	EP Model No.	Application/Emission	No. of Sources	Design Vol. Flow (std. cfm, dry)	Performance Guarante - dust concentration (grains/scfd)
1.	7/82-7/83	Georgia Pacific Dudley, NC	3-600 (WEP)	Green Flake Chip Dryers/ Flyash, Condens. Organics	3	121,429	0.017
2.	5/84-9/85	Georgia Pacific Skippers, VA	3-900 (WEP)	Green Flake Chip Dryers Flyash, Condens. Organics	4	170,736	0.017
3.	12/84-4/86	Collins Pine Chester, CA	2-550 (WEP)	Wood Boiler/Chip Dryer (Dutch oven) flyash, Condensing organics	3	86,084	0.023
4.	8/87-	Georgia Pacific Woodland, Maine	3-525 (WEP)	Green Flake Chip Dryer Flyash, Condens. Organics	2	66,600	0.014

A-4

MOBILE PRECIPITATOR* TESTS

No.	Dates: Start/Finish	Customer/Location	Primary Emission	Number of Stack Tests
1.	8/12-9/19/81	Champion International Gayloard, MI	Flyash, Condens. Organics	54
2.	9/29-10/30/81	Georgia Pacific Corp. Dudley, NC	Flyash, Condens. Organics	20
3.	7/28-8/28/84	Collins Pine Chester, CA	Wood Boiler flyash, Condensible organics from dryer	61

APPENDIX B.

WEYERHAEUSERS' EFB TEST DATA

- Moncure, North Carolina

ENTROPY
ENVIRONMENTALISTS INC

POST OFFICE BOX 12291
RESEARCH TRIANGLE PARK
NORTH CAROLINA 27709-2291
919-781-3550

STATIONARY SOURCE SAMPLING REPORT

REFERENCE NO. 6041A

WEYERHAEUSER COMPANY

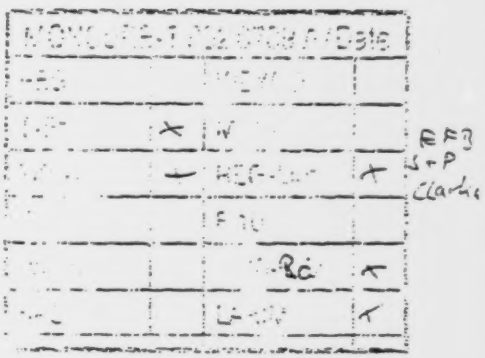
MONCURE, NORTH CAROLINA

PARTICULATE EMISSIONS AND PLUME OPACITY TESTING

SURFACE LINE ELECTRIFIED

FILTER BED INLET AND STACK

Performed For: Carl Schenck, AG



OCTOBER 20, 1988

INTRODUCTION

1.1 Outline of Test Program. Stationary source sampling was performed for Carl Schenck, AG at Weyerhaeuser Company in Moncure, North Carolina, on October 20, 1988. Three sets of concurrent EPA Method 5 runs were performed at the surface line electrified filter bed (EFB) inlet and stack to determine the particulate emissions. The particulate emissions results were used to determine the EFB capture efficiencies. Along with the Method 5 testing, concurrent EPA Method 9 testing was performed at the stack to determine the plume opacity. The testing was conducted for compliance and guarantee purposes.

1.2 Test Participants. Table 1-1 lists the personnel present during the test program.

TABLE 1-1
TEST PARTICIPANTS

Carl Schenck, AG	Fritz Bossler Test Coordinator
Laboratorium Himmelheber GmbH & Co., KG	Gerhard C. Trutter, Dipl. Ing. FH Test Coordinator
Schenkmann & Piel GmbH & Co., KG	Alfred H. Schenkmann Test Observer
Clarke's Sheet Metal, Inc.	Bill Firneisz Test Observer
North Carolina Department of Natural Resources and Community Development	David Y. Daniel Test Observer
Entropy Environmentalists, Inc.	Neill M. Harden Project Manager
	Barry F. Rudd Sampling Team Leader
	W. Todd Langdon Sampling Team Leader
	Dennis D. Holzschuh Engineering Technician
	Leslie C. Murray Engineering Technician
	Keith R. Hazel Plume Opacity Observer

SUMMARY OF RESULTS

2.1 Presentation. Table 2-1 presents test results and EFB/baghouse capture efficiencies for the testing performed October 20, 1988, at the surface line EFB inlet and stack. Run-by-run summaries for the EFB inlet and stack particulate tests are presented in Tables 2-2 and 2-3, respectively. The plume opacity summary is presented in Table 2-4. Detailed test results are presented in Appendix A; field and analytical data are given in Appendix B.

2.2 Guarantee Allowable Emissions. The allowable filterable particulate concentration is 0.065 and 0.004 grains per actual cubic foot (Gr/ACF) for the EFB inlet and stack, respectively. The allowable plume opacity is 20%.

TABLE 2-1

TEST RESULTS AND EFB/BAGHOUSE CAPTURE EFFICIENCIES

Surface Line EFB Inlet and Stack

	Test Set 1	Test Set 2	Test Set 3	Average
EFB Inlet				
Concentration, Gr/ACF				
Filterable	0.0398	0.0371	0.0289	0.0353
Emission Rate, lb/hr				
Filterable	21.7	20.4	15.4	19.2
Stack				
Concentration, Gr/ACF				
Filterable	0.00279	0.00254	0.00142	0.00225
Emission Rate, lb/hr				
Filterable	1.52	1.40	0.775	1.23
Plume Opacity				
Highest 6-min. Average, %	7	1	5	
Highest Single Reading, %	10	5	15	
EFB Capture Efficiency, %*	93.00	93.14	94.97	93.70

* Capture efficiency (CE) calculated as follows:

$$CE = \frac{\text{Inlet Emission} - \text{Stack Emission}}{\text{Inlet Emission}} * 100$$

$$CE = \frac{21.7 - 1.52}{21.7} * 100 = 93.00\ \%$$

Note: Capture efficiencies calculated using filterable emission rates.

TABLE 2-4

SIX-MINUTE AVERAGE PLUME OPACITY OBSERVATIONS SUMMARY

Surface Line Stack

Run Number	M9-SL-O-1	M9-SL-O-2	M9-SL-O-3
Highest 6-Minute Average Opacity, %	7	1	5
Highest Single Opacity Reading, %	10	5	15

------ Run M9-SL-O-1 ------

Set No.	--- Time --- Start	End	Avg. % Opacity
1	1133	1139	0
2	1139	1145	1
3	1145	1151	1
4	1151	1157	D
5	1157	1203	7
6	1203	1209	4
7	1209	1215	4
8	1215	1221	4
9	1221	1227	4
10	1227	1233	2

------ Run M9-SL-O-2 ------

Set No.	--- Time --- Start	End	Avg. % Opacity
1	1306	1312	1
2	1312	1318	0
3	1318	1324	0
4	1324	1330	0
5	1330	1336	0
6	1336	1342	0
7	1342	1348	0
8	1348	1354	0
9	1354	1400	0
10	1400	1406	0

------ Run M9-SL-O-3 ------

Set No.	--- Time --- Start	End	Avg. % Opacity
1	1442	1448	0
2	1448	1554	0
3	1554	1600	P
4	1600	1606	P
5	1606	1612	0
6	1612	1618	0
7	1618	1624	5
8	1624	1630	P
9	1630	1636	P
10	1636	1642	3

D = Interference from dust cloud emitted from device at base of stack.

P = Interference from plume emitted from other stack.

PROCESS DESCRIPTION AND OPERATION

3.1 General. Weyerhaeuser Company in Moncure, North Carolina operates surface line and core line sander dust burners for drying wood chips. For this program, the surface line was tested.

The primary fuel for the surface line burner is 100% sander dust. Potential emissions include the products of complete and incomplete combustion of the fuel and any extraneous materials present. The emissions are controlled by four cyclones, an electrified filter bed,

3.2 Source Air Flow. Figure 3-1 is an air flow schematic showing the passage of the flue gases through the surface line.

3.3 Operation During Testing. The method for determining the system feed rate is accompished by measuring the dryer conveyor belt speed. According to Weyerhaeuser Company, the surface line was operated at an average setting of 80% during testing, which is the maximum capacity setting. The maximum load is 17,000 pounds per hour. Thus, the feed rate during testing is calculated as follows:

(0.80 / 0.80) * 17,000 = 17,000 pounds per hour

SAMPLING AND ANALYTICAL PROCEDURES

4.1 General. All sampling and analytical procedures were those recommended by the United States Environmental Protection Agency and the North Carolina Department of Natural Resources and Community Development. Descriptions of the sampling equipment and procedures (extracted from 40 CFR 60) are provided in Appendix D.

4.2 Sampling Points. The number and location of the sampling points were determined according to EPA Method 1. The EFB inlet cross section was divided into 24 equal areas with 12 sampling points on each of two traverse axes, as shown in Figure 4-1. The stack cross section was divided into 12 equal areas with six sampling points on each of two traverse axes, as shown in Figure 4-2.

4.3 Volumetric Air Flow Rates

4.3.1 Flue Gas Velocity. EPA Method 2 was used to take the velocity measurements during the traverses of the EFB inlet and stack cross sections.

4.3.2 Flue Gas Composition. Multipoint, integrated flue gas samples were collected at the stack and analyzed using EPA Method 3 to determine the flue gas composition and molecular weight for each run. The results were also used for the EFB inlet.

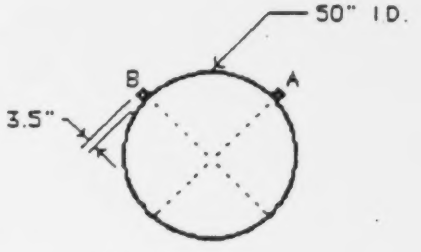
4.3.3 Flue Gas Moisture. Moisture content was determined by analyzing the sampling train impinger reagents according to the procedures outlined in EPA Method 5.

4.4 Emissions Determinations. EPA Method 5 sampling procedures were used to determine the particulate emissions. At the EFB inlet, each of the 24 points was sampled for 2.5 minutes, resulting in a net run time of 60 minutes. At the stack, each of the 12 points was sampled for five minutes, also resulting in a net run time of 60 minutes.

4.4.1 Filterable. EPA Method 5 analytical procedures were used to analyze the filterable particulate.

TRAVERSE POINTS

2 AXES
12 POINTS/AXIS
24 TOTAL POINTS



SECTION M-M

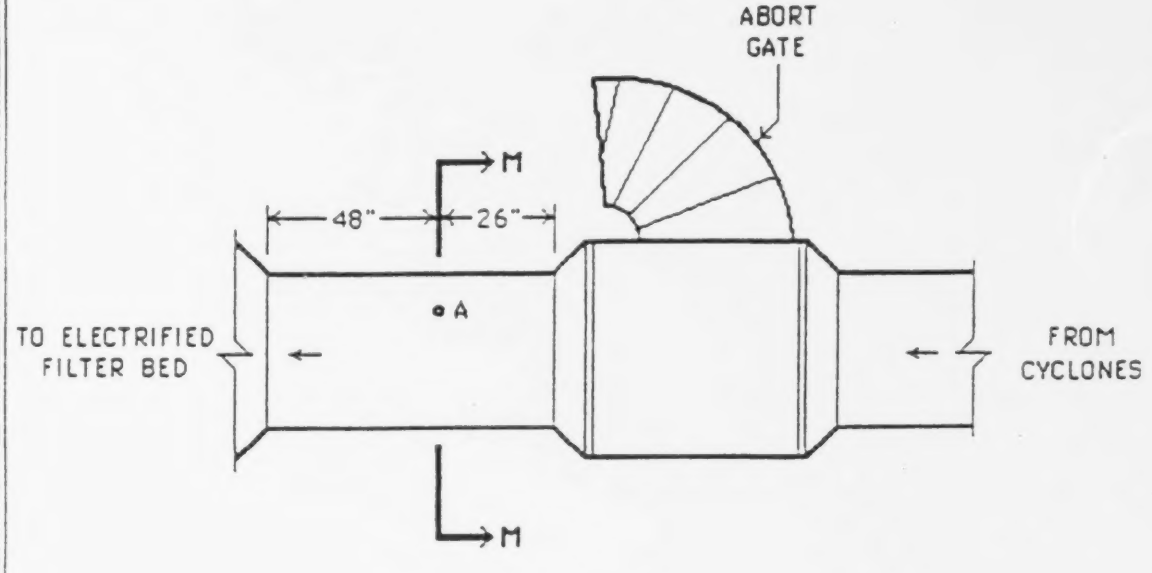
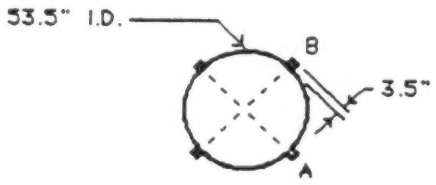


FIGURE 4-1. SURFACE LINE ELECTRIFIED FILTER BED INLET TEST LOCATION.

TRAVERSE POINTS

2 AXES
6 POINTS/AXIS
12 TOTAL POINTS



SECTION N-N

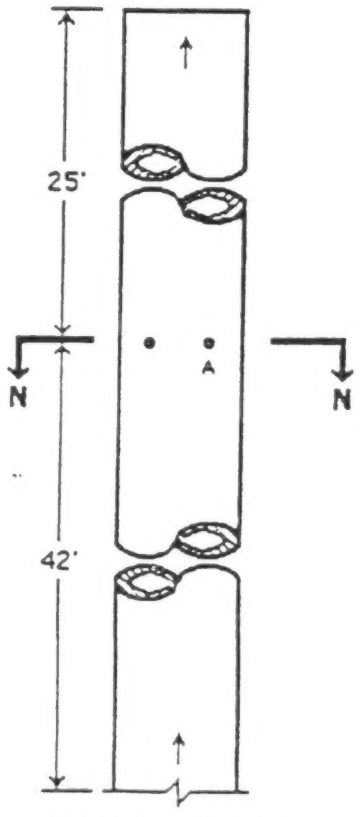


FIGURE 4-2. SURFACE LINE STACK TEST LOCATION.

4.4.2 Condensable. The sampling train distilled water reagent and acetone rinses were analyzed to determine the condensable particulate emissions. For each run, the impingers' water was extracted three times with chloroform and then extracted three times with ether. The acetone rinses and the pooled chloroform and ether phases were evaporated to dryness at room temperature and desiccated. After extraction, the water phase was evaporated to dryness on a steam bath and desiccated. Following desiccation, a gravimetric analysis was performed on each phase to determine the weight of the residue.

4.5 Plume Opacity. The procedures outlined in EPA Method 9 were followed in determining the plume opacity.

4.6 Equipment Calibration. Pertinent calibration data are provided in Appendix C.

APPENDIX C.

GEORGIA-PACIFIC's ESP TEST DATA

- Dudley, North Carolina
- Skippers, Virginia
- Woodland, Maine

TABLE C-1. PARTICULATE SAMPLING AT INLET OF WET ESP.
GEORGIA-PACIFIC - DUDLEY, NORTH CAROLINA

Run Number	1	2	4
Date	9/20/83	9/20/83	9/21/83
% Isokinetcs	108.48	102.54	101.83
% Excess Air	1016.5	1117.0	861.6
Volume of Gas Sampled, SCF* Dry	25.825	24.977	25.312
Stack Gas Flow Rate, SCFM* Dry	96,543	96,583	97,454
Stack Gas Flow Rate, ACFM	135,560	132,430	137,230
Particulates: **			
Catch, mgrams	165.59	119.79	156.03
Concentration, grains/ SCF* Dry	0.0988	0.0739	0.0949
Emission Rate, lbs/hr	81.70	61.13	79.29

* 68°F, 29.92 in. Hg.

** Front half only

TABLE C-2. PARTICULATE SAMPLING AT OUTLET OF WET ESP.
GEORGIA-PACIFIC - DUDLEY, NORTH CAROLINA

Run Number	1	2	4
Date	9/20/83	9/20/83	9/21/83
% Isokinetic	98.83	95.03	101.76
% Excess Air	1016.5	1117.0	861.6
Volume of Gas Sampled SCF* Dry	67.224	66.688	68.054
Stack Gas Flow Rate, SCFM* Dry	87,589	88,277	88,882
Stack Gas Flow Rate, ACFM	117,810	118,003	118,470
Particulates: **			
Catch, mgrams	44.85	41.32	33.79
Concentration, grains/ SCF* Dry	0.0103	0.0095	0.0077
Emission Rate, lbs/hr	7.712	7.219	5.824

* 68°F, 29.92 in. Hg.

** Front half only

TABLE C-3. TEST SUMMARY AT GEORGIA-PACIFIC'S PLANT IN SKIPPERS, VIRGINIA.

SYSTEM: GEORGIA PACIFIC CORPORATION
SKIPPERS, VIRGINIA
ESP FOR CHIP DRYING PROCESS

TEST DATE: APRIL 20, 1989

	INLET				OUTLET			
PARAMETER	RUN #1-I	RUN #2-I	RUN #3-I	AVERAGE	RUN #1-O	RUN #2-O	RUN #3-O	AVERAGE
GENERAL								
Qs, FLOW, ACFM	191240	199280	197975	196165	175481	196836	176021	182779
Qs dry, FLOW SCFM	114227	123895	114814	117645	114528	121743	113318	116529
Vm std, CUBIC FT.	44.95	48.45	44.75		46.50	50.38	46.08	
%I	100.1	99.5	99.2		103.3	105.3	103.5	
PARTICULATE MATTER								
PMR AVG, LB/HR	131.5	46.6	303.4	160.5	11.7	14.6	10.8	12.4
Cs, GR/SCF	.1342	.0440	.3096	.1626	.0117	.0137	.0109	.0121
EFFICIENCY, % (BY WEIGHT)					91.1	68.7	96.4	85.4
FORMALDEHYDE								
PMR AVG, LB/HR	9.6	10.0	11.4	10.3	8.0	11.2	11.5	10.2
Cs, GR/SCF	.0098	.0095	.0116	.0103	.0080	.0104	.0117	.0100
EFFICIENCY, % BY WEIGHT)					16.7	-12.0	-0.9	1.3
VOLATILE ORGANIC COMPOUNDS								
PMR AVG, LB/HR	98.1	286.2	177.4	187.2	22.3	168.5	84.6	91.8
EFFICIENCY, % (BY WEIGHT)					77.2	41.1	52.3	56.9

TABLE C-4. TEST SUMMARY AT GEORGIA-PACIFIC'S PLANT IN WOODLAND, MAINE.

SYSTEM	GEORGIA PACIFIC CHIP DRYER INLET WOODLAND, MAINE			
TEST DATE	OCTOBER 25, 1988			
PARAMETER	RUN 1-I	RUN 2-1	RUN 3-I	AVERAGE
Qs, FLOW, ACFM	88135	88387	86270	87597
Qs dry. FLOW SCFM	62735	60425	59797	60986
Vm std, CUBIC FT.	24.01	14.99	15.01	
%I	122.2	110.2	110.3	
PMR AVG, LB/HR DRY CATCH	80.27	54.36	55.95	63.53
DRY AND WET	189.80	126.38	142.73	152.97
Cs, GR.SCF DRY CATCH	0.134	0.0998	0.1038	0.1126
DRY AND WET	0.317	0.232	0.265	0.271
TGNMO LB/HR	83.52	143.21	60.99	
FORMALDEHYDE LB/HR	.1084	.0978	.1294	.1119

TABLE C-4. CONTINUED.

SYSTEM GEORGIA PACIFIC
CHIP DRYER EXHAUST
WOODLAND, MAINE

TEST DATE OCTOBER 25, 1988

PARAMETER	RUN #1-O	RUN #2-O	RUN #3-O	AVERAGE
Qs, FLOW, ACFM	87660.7	83307.7	83186.0	84718.14
Qs dry, FLOW SCFM	56278.9	52692.9	54024.9	54332.2
Vm std, CUBIC FT.	44.12	41.84	42.62	
%I	108.1	109.5	105.7	
PMR AVG, LB/HR DRY CATCH	3.65	3.70	4.31	3.88
DRY AND WET	6.45	6.68	7.65	6.93
Cs, GR/SCF DRY CATCH	.0073	.0078	.0090	.0080
DRY AND WET	0.0128	0.0141	0.0160	0.0143
ALLOWABLE, LB/HR (DRY CATCH ONLY)				8.6*
TGNMO LB/HR	37.99	18.77	19.25	
FORMALDEHYDE LB/HR	.0596	.0495	.0490	.0527

*based on limiting total waferboard plant particulate emissions to 50 Tons/Year or less, and deducting other waferboard plant emissions

TABLE C-4. CONTINUED.

SYSTEM	GEORGIA PACIFIC CHIP DRYER EXHAUST WOODLAND, MAINE	
TEST DATE	OCTOBER 25,1988	
PARAMETER	RUN 4-I	RUN 4-O
Qs, FLOW, ACFM	92199	80824
Qs dry, FLOW SCFM	69788	58344
Vm std, CUBIC FT.	7.81	15.69
%I	107.8	108.9
PMR AVG, LB/HR DRY CATCH	78.28	5.86
DRY AND WET	118.17	7.968
Cs, GR/SCF DRY CATCH	0.126	0.011
DRY AND WET	0.190	0.015
FORMALDEHYDE LB/HR	.0817	.0931

United States Patent [19]

Shinn et al.

[11] Patent Number: 4,729,176

[45] Date of Patent: Mar. 8, 1988

[54] **ROTARY DRUM DRYER AND METHOD**

[75] Inventors: Donald E. Shinn; Andrew D. Livingston, both of Independence, Kans.

[73] Assignee: Productization, Inc., Independence, Mo.

[21] Appl. No.: 33,344

[22] Filed: Apr. 1, 1987

[51] Int. Cl.[4] F26B 3/10; F26B 11/04

[52] U.S. Cl. 34/33; 34/128; 34/129; 34/136

[58] Field of Search 34/33, 108, 109, 127, 34/128, 129, 130, 132, 134, 136; 432/103, 105, 106, 107, 111, 112

[56] **References Cited**

U.S. PATENT DOCUMENTS

1,378,407	5/1921	Fraser .	
1,641,108	8/1927	West .	
1,871,934	8/1932	West et al. .	
1,988,677	1/1935	Arnold	34/5
1,988,678	1/1935	Arnold	34/24
1,996,347	4/1935	Reppert	34/5
2,076,873	4/1937	Arnold	34/5
2,113,047	4/1938	French	285/10
2,132,972	10/1938	Schmidt	34/5
2,295,918	9/1942	Thomas	83/27
2,316,459	4/1943	Schmidt et al.	34/57
2,319,673	5/1943	French	263/32
2,618,865	11/1952	Arnold	34/128
3,097,833	7/1963	Harris et al.	263/32
3,137,546	6/1964	Lamb	34/10
3,410,233	11/1968	Seiler	110/15
3,785,765	1/1974	Rowell et al.	432/107
3,906,961	9/1975	Rowell et al.	131/135
3,916,807	11/1975	Eiki	110/14
3,995,988	12/1976	Freze	432/21
4,237,622	12/1980	Francis	34/147
4,259,081	3/1981	Reuter et al.	23/293
4,376,343	3/1983	White et al.	34/109
4,477,984	10/1984	Wenger	34/128
4,506,453	3/1985	Shirley, Jr. et al.	34/12

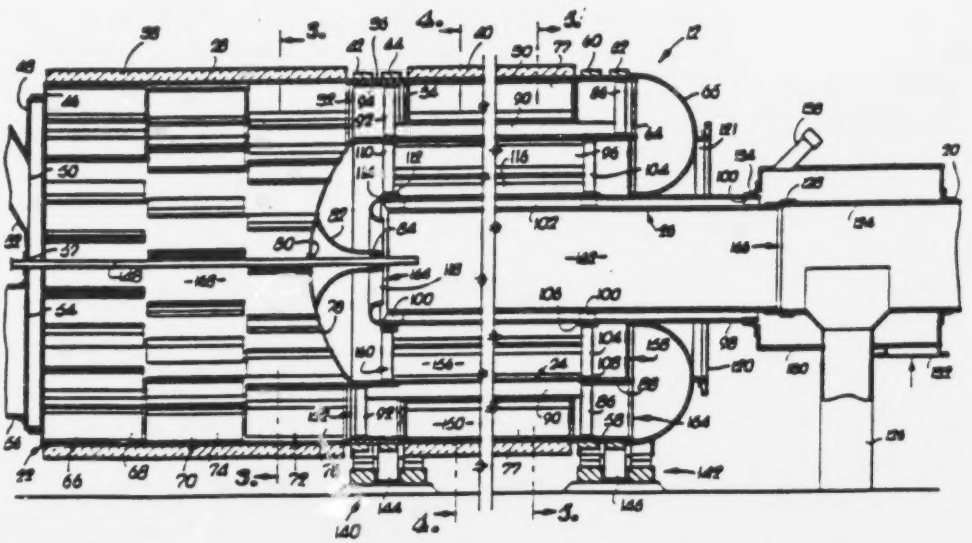
Primary Examiner—Larry I. Schwartz

Attorney, Agent, or Firm—Schmidt, Johnson, Hovey & Williams

[57] **ABSTRACT**

An improved, high efficiency rotary drum dryer and method is disclosed which achieves outstanding thermal efficiencies by provision of a multiple-pass rotary dryer designed so that the product to be dried is first conveyed through an outermost drum of relatively large cross-sectional area and then through succeeding internal drums of progressively smaller cross-sectional areas. In this way, the velocity of induced air currents traveling through the dryer increases from pass to pass, with the result that the net velocity of product through successive passes also increases. The preferred dryer also includes housing structure in surrounding relationship to the innermost drum permitting introduction of relatively low humidity ambient-derived air into the central drum so as to lower the partial pressure of moisture in the drying atmosphere, thus promoting the final stage of drying. The preferred dryer also includes an assembly for selective introduction of a liquid or solid product treating agent into the final central drum. The dryer of the invention is capable of drying a greater volume of material with a shorter dryer and increased efficiencies are obtained because of increased airflow without attendant settling out of larger particles and possible dryer plugging.

11 Claims, 5 Drawing Figures



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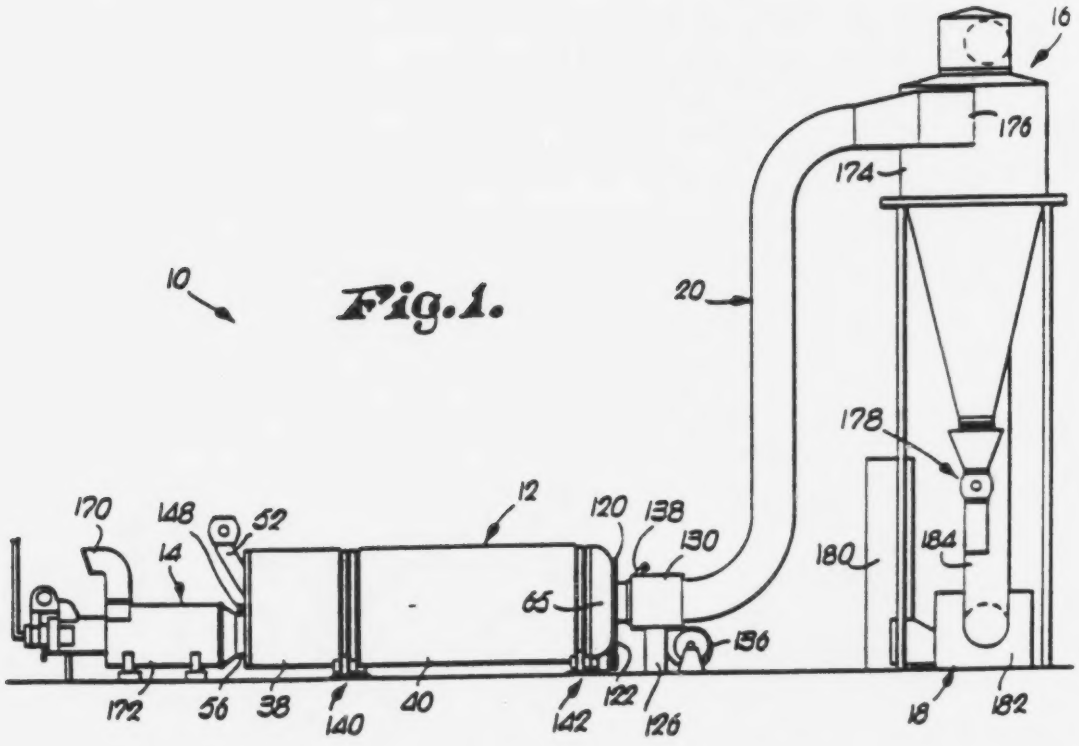
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Fig.1.

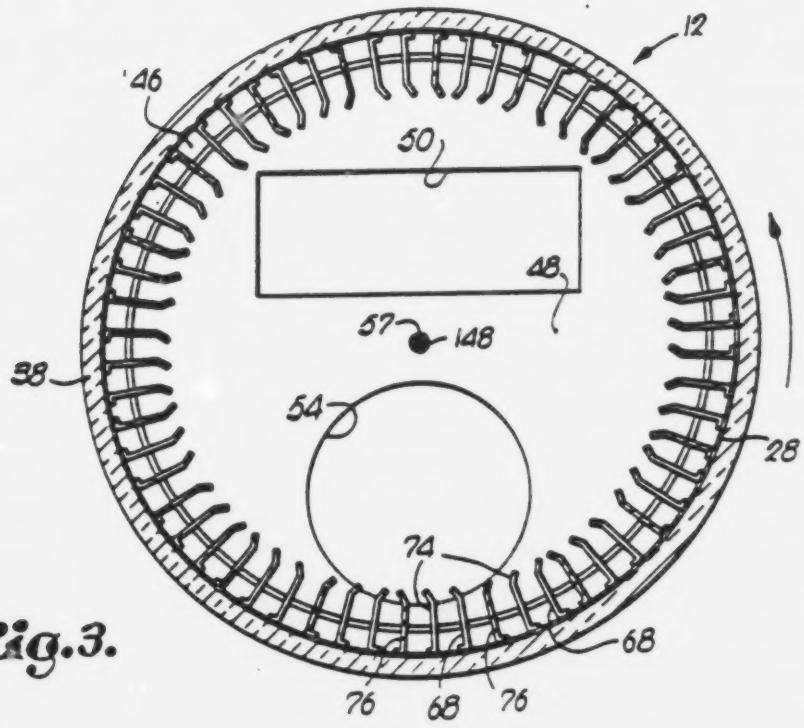
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Fig.3.

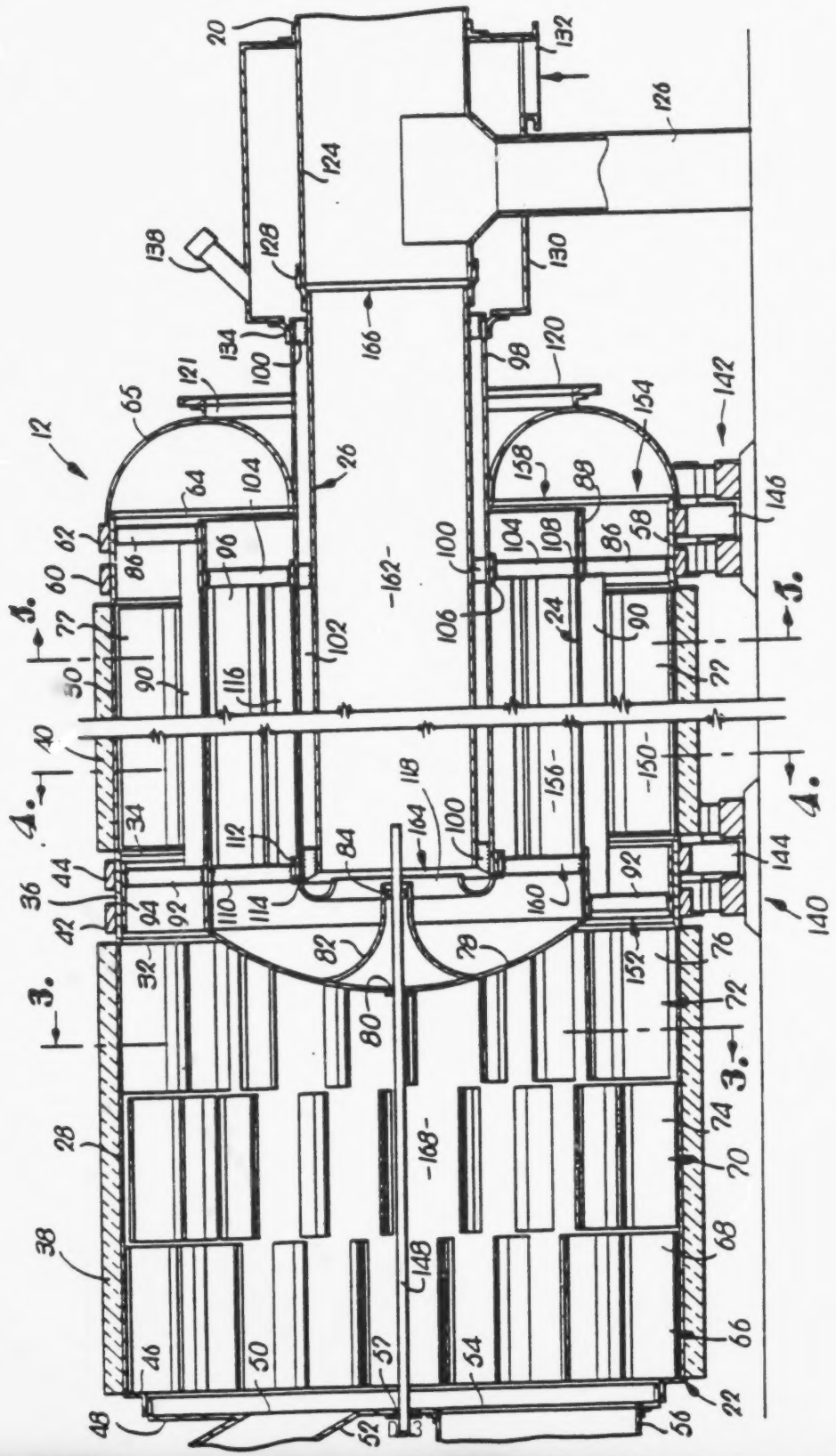
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Fig. 2.

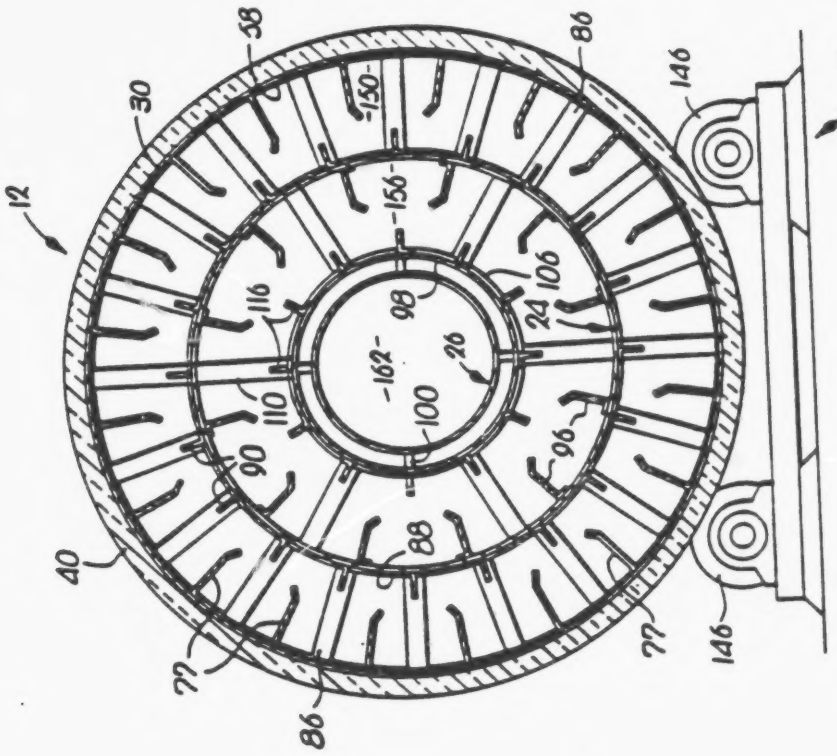
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Fig.5.

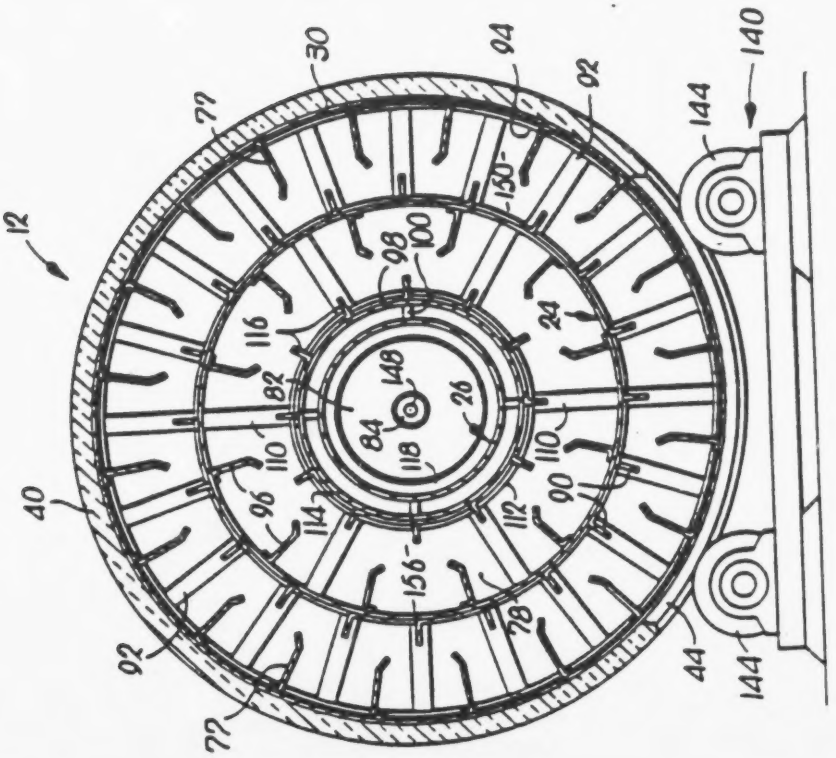
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Fig.4.

ROTARY DRUM DRYER AND METHOD

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention is broadly concerned with an improved multiple-pass dryer useful for drying a variety of particulates such as wood furnish and agricultural products. More particularly, it is concerned with such a dryer apparatus which achieves substantially increased efficiency through use of an internal flow path arrangement serving to direct incoming, initially wet product along a serpentine flow path beginning in an outermost, relatively large cross-sectional area passageway and proceeding to successively smaller cross-sectional area passageways until dried product is removed from the apparatus. In this fashion the velocity of air currents within the drying apparatus increases as the currents pass through the dryer, whereby the velocity differential between such air currents and the saltation velocities of the particles being dried is maintained for maximum drying effect, and the net velocity of the particles moving through the dryer increases. In other aspects of the invention, apparatus is provided for the introduction of relatively dry ambient air into the innermost dryer drum to reduce the partial pressure of water vapor of the air currents passing through the dryer to increase final stage drying in the apparatus. Binders or other treating agents may also be added to the products during the final stage of drying through use of a novel addition conduit extending into the central drum of the dryer.

2. Description of the Prior Art

The drying of wood or agricultural particulates in a multiple-stage dryer is dependent upon a large number of factors, e.g., the type of product to be dried, the initial moisture content thereof, particle geometry, variable ambient conditions, dryer configuration and fuels being employed. Considerable research has been conducted in the past toward achieving maximum dryer efficiency, but in view of the relatively complex nature of the problem, the ideal dryer has yet to be developed.

In general however, the drying process involves several distinct phases or stages. That is to say, most hygroscopic materials exhibit several distinct drying rate periods as they pass through a multiple-pass dryer. Initial drying is accompanied by a warming of the material and its attendant moisture. The drying rate increases during this initial period, while the moisture content drops to a value which signals the beginning of a constant rate period of drying. During the constant rate period, moisture is evaporated from the surface of product particles at a steady rate until the surfaces are no longer entirely wet. Thereafter, a falling-off period obtains where the drying rate decreases because of the increasing difficulty of moving internal product moisture to the particle surfaces where it can be taken up and moved away. Finally, the product moisture is reduced to a point where an equilibrium is established with the surrounding atmosphere.

Conventional three-pass dryers include an elongated, horizontal, axially rotatable body having an outer drum and a series of concentric, smaller diameter drums within the outer drum. The respective drums are in communication with each other and define a serpentine flow path to the dryer. Without known exception, such dryers are provided with a product inlet oriented for directing initially wet product and hot drying air into the innermost, smallest diameter drum, whereupon the product is conveyed via induced draft currents through the outer drums until it reaches a passageway defined by the outer drum and the next adjacent inboard drum. At this point the product is in its final dried condition and is delivered for further handling or collection. Thus, conventional three-pass cylindrical dryers utilize comparatively high air velocities and temperature conditions in the innermost drum (first pass) where the incoming products are the heaviest and the wettest. Lower air velocities and lower temperatures obtain in the intermediate drum (second pass), and even lower velocities and temperatures exist in the outer drum (third pass).

This "inner drum to outer drum" configuration of conventional dryers is employed because it is believed that surface moisture evaporation is maximized in a relatively small cross-sectional area central drum where the highest air current velocity and temperature conditions exist. In the succeeding, larger diameter outer drums, it is believed that further drying is accomplished by phenomena characteristic of the falling drying rate phase. Also, the theory of conventional dryers is that the slower moving air currents in the outer drums allow larger particles to settle out and permit smaller particles to pass through, at least until the larger particles are dried enough to be picked up and conveyed by prevailing air currents.

In practice though, the relatively high air current velocity conditions in the first pass of a conventional dryer cause the wet particles to be quickly driven away from the heat source, and there is consequently a reduced opportunity for adequate heat transfer and evaporation. In subsequent passes with lower air current velocities, the particles may settle out because the prevailing air current velocities fall below the saltation velocity of the product (i.e., the minimum air current velocity needed to pick up and convey product at a given moisture level). Thus, plugging of the dryer may occur, particularly at high product flow rates, and at best the product only moves at a rate determined by the forward velocity of the slowest moving (largest) particles. The result is that the flow rate must be decreased and this inevitably has an adverse effect on drying efficiency.

SUMMARY OF THE INVENTION

The present invention overcomes the problems described above and provides a unique dryer construction and method providing high drying efficiencies and the consequent ability to dry relatively large quantities of product in a small dryer utilizing reduced amounts of fuel.

Broadly speaking, the multiple-pass dryer of the invention reverses the normal dryer flow path and provides that incoming, initially wet product is directed to an outer drum having a relatively large effective cross-sectional area, whereupon the product and attendant air currents pass inwardly through drums of successively smaller effective cross-sectional areas, so that the product exits from the smallest diameter central drum.

In more detail, the preferred dryer includes an elongated, normally horizontally disposed, axially rotatable body having means defining a plurality of elongated internal passageways in communication with each other to present a continuous, serpentine flow path through the body. Advantageously, these passageways are sub-

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stantially concentric and each presents a different effective cross-sectional area. A product inlet is oriented for initially directing product to be dried into an outer passageway having a relatively large effective cross-sectional area. Further, means is provided for creating currents of heated air within the body and along the flow path for conveying the product along the flow path through the relatively large effective cross-sectional area passageway, and then toward and through the smaller effective cross-sectional area passageways. A product outlet is provided in communication with a passageway having a relatively small effective cross-sectional area, generally the smallest diameter central passageway. Thus, the dryer of the invention effectively employs the novel principle of "outer drum to inner drum" operation.

In other aspects of the invention, means is provided for introducing quantities of relatively dry ambient-derived air into the innermost passageway of the dryer body, so as to lower the partial pressure of water within the air currents traveling through the dryer, thus enhancing the final stages of drying. Preferably, an elongated, rotatable tubular element is concentrically disposed about the innermost drum of the dryer to define therewith an elongated, annular zone; and an annular, arcuate, inturned air-directing flange is located at the entrance of the inner drum so as to direct the ambient air into and along the length of the passageway defined by the inner drum.

The present invention also provides apparatus for the introduction of a liquid or solid additive (e.g., water, wax, resins or organic binders) into the innermost drum passageway. Such apparatus is advantageously in the form of an elongated, rigid, non-rotating tube extending into the inner passageway adjacent the entrance end thereof.

In practice, dryers in accordance with the present invention achieve measurably increased drying efficiencies. This obtains by virtue of the "outer drum to inner drum" operation thereof which serves to successively increase the velocity of the air currents traversing the serpentine dryer flow path. This ensures that the product has an increased average net velocity in each of the successive drum passageways. As explained, this is very different from conventional dryers, wherein the average net velocity of the product decreases from passageway to passageway.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a side elevational view of a complete product drying apparatus in accordance with the present invention.

FIG. 2 is a fragmentary view in vertical section illustrating the construction of the preferred drum dryer of the invention;

FIG. 3 is a sectional view taken along line 3—3 of FIG. 2;

FIG. 4 is a sectional view taken along line 4—4 of FIG. 2; and

FIG. 5 is a sectional view taken along line 5—5 of FIG. 2.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Turning now to the drawings, and particularly FIG. 1, a drying system 10 is illustrated which broadly includes a three-pass drum dryer 12 of improved construction, together with a burner 14 for supplying hot drying air to the dryer 12. In addition, the system 10 includes a cyclone separator assembly 16 having an induced draft fan unit 18 and a conduit 20 leading from the outlet of dryer 12 to the inlet of the assembly 16.

Turning now to FIGS. 2–5, it will be seen that the dryer 12 broadly includes an outer drum 22 together with a pair of internal, concentrically disposed drums 24, 26. It will be noted in this respect that the drum 22 is substantially longer than the intermediate drum 24 and central drum 26, and the importance of this feature will be explained hereinafter.

In any event, outer drum 22 is in the form of an elongated, tubular metallic body made up of a pair of circular in cross-section, elongated members 28 and 30 oriented in end-to-end relationship. As best seen in FIG. 2, the right-hand end of member 28 is beveled as at 32, and correspondingly the lefthand end of member 30 is beveled as at 34. A relatively short, circular in cross-section mounting ring 36 of increased thickness is interconnected with the respective adjacent beveled ends 32, 34 of the drum-defining members 28, 30, as will be readily seen. Each of the members 28, 30 is covered by external thermal insulation as at 38, 40. Ring 36 is provided with a pair of laterally spaced apart, outwardly extending metallic tracks or tires 42, 44, the function of which will be described.

The lefthand or inlet end of outer drum 22 is provided with an annular angle flange 46 (see FIG. 2) which is affixed to the extreme end of the drum member 28. A stationary circular head 48 is received by flange 46 as illustrated, and covers the end of outer rotatable drum 22. Head 48 is provided with a large, rectangular product inlet opening 50 and an integral, upwardly and obliquely extending product inlet chute 52. Moreover, head 48 includes a lower, circular inlet opening 54 for the introduction of heated drying air into the dryer. For this purpose, a tubular collar-type connector 56 is affixed to head 48 in registry with opening 54, and is designed to mate with the outlet of burner 14. Finally, the head 48 includes a central opening 57 therethrough sized to accommodate a liquid additive conduit.

The opposite end of drum 22 is provided with a mounting ring 58 similar to the ring 36. Thus, the ring 58 is of circular cross-section, but has a thickness greater than that of the adjacent drum-defining member 30. Further, the extreme righthand end of the member 30 is beveled to facilitate connection of ring 58 thereto; and the ring 58 is provided with a pair of annular, outwardly extending mounting tires 60, 62. The outermost righthand end of the ring 58 is beveled as at 64, and the end of the drum 22 is in part closed by provision of a semi-torroidal end wall 65 affixed to the beveled end of the beveled righthand end of ring 58.

The drum-defining member 28 is provided with three series of laterally adjacent, circumferentially spaced apart internal flights. Referring particularly to FIGS. 2 and 3, it will be seen that a series 66 of flights is provided adjacent head 48 and includes a plurality of inwardly extending flight members 68 spaced about the interior of the member 28. In a similar fashion, flighting series 70 and 72 are provided, respectively having circumferentially spaced apart, inwardly extending flighting elements 74 and 76. The purpose of the internal flighting within drum-defining member 28 is to initially separate and "shower" incoming, initially wet product to the dryer.

On the other hand, the adjacent drum-defining member 30 has a single series of elongated, circumferentially

spaced apart, inwardly extending flights 77 which are respectively affixed to the inner face of the member 30 (see FIGS. 2, 4 and 5).

The intermediate drum 24 is in the form of an elongated, circular in cross-section metallic element extending essentially the entire axial length of ring 36, member 30 and ring 58, but of a smaller diameter. An arcuate in cross-section, concavo-convex end wall 78 is attached to the lefthand end of drum 24 as seen in FIG. 2, with end wall 78 being provided with a central aperture 80 therethrough. End wall 78 further has a smoothly arcuate diverter 82 affixed to the face thereof remote from head 48 and extending toward the opposite end of the dryer 12. The diverter 82 includes an apertured bearing 84 adjacent the apex thereof, which is important for purposes to be described.

Intermediate drum 24 is supported within the drum-defining member 30 by means of a plurality of radially extending, circumferentially spaced apart struts 86 located adjacent the right-hand end of the drum 24 as viewed in FIG. 2. In particular, it will be seen that a circular reinforcing plate 88 is secured to the extreme right-hand end of the drum 24, with the struts 86 being welded to and extending radially outwardly from plate 88. The outboard ends of the struts 86 are welded to the inner face of guide ring 58. In order to provide further strength and rigidity, elongated, axially extending angle ribs 90 are affixed to the outer face of drum 24 and are oriented in a circumferentially spaced relationship (see FIG. 5). In this respect, it will be noted that the angles 90 are oriented with the struts 86.

The opposite end of drum 24 adjacent end wall 78 is likewise supported by means of radially outwardly extending, circumferentially spaced apart struts 92. These struts are welded to end wall 78 as shown and extend outwardly therefrom. The outboard ends of the struts 92 are also welded to a circular ring 94 which is situated adjacent the inner face of mounting ring 36. However, there is no interconnection between the rings 94, 36, in order to accommodate thermal expansion and contraction of the components making up the dryer 12.

The inner face of drum 24 has a series of lifting and separating flights 96 which are oriented in circumferentially spaced relationship and extend inwardly toward the center of drum 12.

Central drum 26 is in the form of a tubular metallic body extending substantially the length of the member 30 but projecting beyond the end of the latter for a short distance as illustrated in FIG. 2. A circular in cross-section, radially enlarged housing 98 is concentrically disposed about drum 26, and is fixedly secured thereto by means of a series of spacers 100. Thus, an elongated, annular zone 102 is defined between the exterior face of drum 26 and the interior face of housing 98.

The drum/housing composite made up of the interconnected drum 26 and housing 98 is supported adjacent the righthand end of dryer 12 as seen in FIG. 2 by means of plural, circumferentially spaced, radially outwardly extending struts 104. The struts 104 are welded to a narrow, circular reinforcing ring 106, the latter being in turn welded to the outer face of housing 98. The opposite ends of the struts 104 are welded to the inner face of drum 24 as at 108.

The inner, lefthand end of drum 26 is supported by plural, circumferentially spaced apart, radially outwardly extending struts 110. In this case, the respective struts 110 are welded to a narrow circular ring 112 which is positioned in closely adjacent, surrounding relationship to a similarly dimensioned ring 114 secured to the extreme lefthand end of housing 98. However, there is no mechanical connection between the adjacent rings 112, 114.

The outer face of housing 98 carries a plurality of reinforcing angle ribs 116 which extend between the struts 104, 110 as depicted. These ribs 116 are oriented in an evenly circumferentially spaced fashion about housing 98. Also, the inner circular margin of end wall 65 is affixed to housing 98 as illustrated.

The inboard end of housing 98 includes a circular, arcuate in cross-section diverter 118 which is affixed to the housing and extends inwardly beyond drum 26 so that air passing through the zone 102 is diverted for passage into and along the length of central drum 26.

A drive sprocket 120 having a reinforcing angle 121 bolted thereto is secured by means of welding to the wall 65, in order to rotate the central drum 26 and, by virtue of the described interconnections, the entirety of drum 12. For this purpose, the overall drum assembly includes a chain 122 trained around sprocket 120, with the chain being operatively coupled to a drive motor.

The extreme righthand end of drum 26 terminates adjacent a stationary plenum box 124. The box 124 includes a heavies drop-out chute 126, and is coupled to conduit 20. Further, a flexible seal 128 is provided between the end of drum 20 and the inlet of stationary box 124 to effect a rotating seal between these members.

An enlarged secondary plenum box 130 is disposed in surrounding relationship to box 124 and is provided with a lower ambient air inlet 132. A flexible seal 134 is provided between the extreme righthand end of housing [illegible] the outlet of plenum box 130. A blower assembly [illegible] see FIG. 1) is situated below box 130 and is operatively coupled to air inlet 132. Finally, box 130 is equipped with a water injection port 138 so as to permit selective injection of moisture into air currents within the outer plenum box.

The complete dryer 12 is mounted for axial rotation by means of a pair of mounting assemblies 140, 142 respectively located beneath the rings 36, 58. Each of the mounting assemblies 140, 142 includes a pair of spaced apart, axially rotatable trunnions 144 and 146. The trunnions 144, 146 are respectively in engagement with the tires 42, 44 and 60, 62. The preferred drum mounting structure used in the preferred embodiment of the invention is fully described in copending Application for U.S. patent Ser. No. 877,531, filed June 23, 1986 and entitled "Mounting Structure for Rotary Drum Dryer." This application is incorporated by reference herein.

Dryer 12 is also provided with an elongated addition conduit 148 which extends from a point outside of the dryer through opening 57 of head 48 and member 28. The inner end of the conduit 148 is received by bearing 84, and extends to a point just inside the lefthand end of central drum 26 (see FIG. 2). Conventional metering equipment may be coupled to the exterior end of conduit 148 for the purpose of metering liquid or solid additives into drum 26 as desired.

From the foregoing discussion, it will be appreciated that the overall drum assembly 12 presents an elongated, normally horizontally disposed, axially rotatable body with the drums 22, 24 and 26 cooperatively defining a plurality of internal passageways intercommunicated to present a continuous serpentine flow path. In particular, it will be seen that dryer 12 includes an elongated, annular in cross-section outermost flow passage-

way 150 having an entrance end 152 and an exit end 154 which is defined between the member 30 and drum 24; an elongated, annular in cross-section intermediate passageway 156 having an entrance end 158 and an exit end 160 and being defined between drum 24 and housing 98; and an innermost, central, circular in cross-section passageway 162 presenting an entrance end 164 and an exit end 166. Moreover, the member 28 and head 48 cooperatively define a large premixing zone 168 for initially wet product and heated air. As will be readily appreciated, provision of walls 65 and 78 ensures that flow of product and air currents through the dryer 12 must proceed through the passageways 150, 156 and 162, rather than being short circuit directly to any of the inner passageways. In general therefore, product to be dried and induced air currents first pass through premixing zone 168 and thence in serial order through outer passageway 150, intermediate passageway 156 and central passageway 162 before leaving the dryer via exit end 166.

Burner 14 is of essentially conventional construction and may be any one of a series of commercially available burners. In general, the burner 14 would include an air inlet 170 leading to a fuel-fired burner chamber 172 which communicates with connector 56. One burner useful in the context of the present invention is that sold by Guaranty Performance Co. of Independence, Kan. as a "ROEMMC" burner.

Assembly 16 includes a conventional cyclone separator 174 having an inlet 176 and a lower product outlet 178. The separator 174 is located in an elevated position, and conduit 20 extends between plenum box 124 and inlet 176, as those skilled in the art will readily appreciate.

Fan unit 18 is positioned at grade and includes a large industrial fan 180 having an air outlet stack 182. The inlet to fan 180 is connected to the upper end of cyclone 174 by means of upright conduit 184. In operation, fan unit 18 serves to draw ambient air into burner chamber 172 through inlet 170, whereupon such air is heated and pulled through the previously described internal flow path of a dryer 12. Inasmuch as product is simultaneously delivered to dryer 12 (advantageously in a dispersed sheet-like fashion through the large opening 50), it will be appreciated that such product is conveyed through the dryer by means of the induced air currents created by fan 18. Furthermore, such negative pressure currents convey dried product from dryer 12 through conduit 20 for ultimate separation in cyclone 174 and later collection.

The described dryer construction gives a number of significant advantages in operation. As is evident from the foregoing, the dryer first of all provides a product flow path which is the reverse of conventional units, i.e., the product passes into and through the outermost passageway 150 and thence through the successive inner passageways 156 and 162. The outer passageway 150 has a maximum effective cross-sectional area, whereas the inboard passageways 156, 162 have progressively smaller effective cross-sectional areas. As a consequence, it will be appreciated that induced air currents passing along the dryer flow path increase in velocity as they proceed from the outer to the inner passageway. This means that the net velocity of the product conveyed along the dryer flow path increases. Thus, while the velocity of product may decrease or vary within a given passageway, the net velocity of the product increases as the product moves to and through the successive passageways.

Provision of the blower assembly 136, plenum box 130, annular zone 102 and diverter flange 118 also permits ready introduction of relatively low humidity, ambient-derived air into the final dryer passageway 162. Thus, if desired relatively dry air from the atmosphere may be directed into entrance end 164 of the passageway 162 for mixing with the heated, humid air currents passing through the final dryer passageway. Inasmuch as a reduction in the humidity of the airstream within passageway 162 causes a corresponding reduction in the partial pressure of the water vapor in the combined airstream, enhanced drying is obtained, because a greater differential vapor pressure between moisture in the product and moisture in the surrounding atmosphere is developed. It will be noted in this respect that the ambient-derived air is preheated within zone 102 by virtue of indirect heating through the walls of housing 98 and drum 26. Furthermore, provision of the diverter 118 ensures that the ambient-derived air enters passageway 162 at a substantial velocity and with sufficient turbulence to promote proper mixing between the low humidity ambient air and the relatively high humidity induced air currents.

If it is desired to add a treating agent in the final passageway 162, such is accomplished through use of the conduit 148. It will be observed in this respect that the outlet end of the conduit 148 is strategically located relative to diverter flange 118 so that the turbulent conditions created adjacent the flange can be employed to enhance mixing of the treating agent with the air/-product stream.

The present invention provides a number of operational advantages which cannot be duplicated in the prior art. In order to illustrate certain of these advantages, the following calculated hypothetical example is provided which compares the drying characteristics of a 12 foot diameter by 60 foot long dryer in accordance with the present invention versus a 12 foot diamter by 60 foot long three-pass dryer of conventional design. Table 1 presents the calculated data for the dryer in accordance with the invention, whereas Table 2 presents corresponding data for the conventional dryer.

TABLE 1

Temperature, Humidity, and Moisture gradients for a 12 ft. diameter by 60 ft. long improved continuous dryer in accordance with the invention:

	Gas Temp. (°F.)	Specific Humidity (%)	Gas Velocity (F/min)	Solids Temp. (°F.)	Solids Moisture (% by wt)	Solids Velocity (f/min)
Pass 1 Station						
0.00	1,100	0.04612	1,376	35	1.00010	24.01
15.00	883	0.07214	2,359	163	0.81312	34.48
30.00	690	0.09867	2,119	212	0.62259	45.14
45.00	477	0.12659	1,812	212	0.42206	56.37
Pass 2 Station						
0.00	284	0.15173	2,381	221	0.24153	57.47
15.00	273	0.15822	2,371	230	0.19486	66.53
30.00	261	0.16471	2,356	240	0.14825	75.62
45.00	250	0.17139	2,345	249	0.10031	84.56
Pass 3 Station						
0.00	212	0.17528	6,149	212	0.07237	3.809
15.00	210	0.15011	7,165	210	0.06151	4.825
30.00	208	0.15138	7,158	208	0.05076	4.818

TABLE 1-continued

45.00	206	0.15264	7.151	206	0.04001	4.811

Drying Process Summary:

	Infeed	Output	
Moisture (%)	1.00010	0.04001	
Solids (lb/hr)	40,000	40,000	
Water (lb/hr)	40,004	1,600	
Total (lb/hr)	80,004	41,600	
Evaporation (lb/hr)		38,404	
Exhaust Air Vol. =		97,501	ACFM
Heat Required[1] =		59,610,115	BTU/hr
Specific Th. Energy[1] =		1,552	BTU/lb evap
Th. Efficiency[1] =		0.7438	

[1]Basis for heat amount is Fuel G.C.V. (gross calorific value)

TABLE 2

Temperature, Humidity, and Moisture gradients for a 12 ft. diameter by 60 ft. long conventional three-pass dryer:

	Gas Temp. (°F.)	Specific Humidity (%)	Gas Velocity (F/min)	Solids Temp. (°F.)	Solids Moisture (% by wt)	Solids Velocity (F/min)
Pass 1						
Station						
0.00	1,100	0.06612	5,044	35	1.00010	652.1
15.00	1,024	0.05480	4,879	83	0.93310	613.4
30.00	951	0.06231	4,706	121	0.87521	573.2
45.00	883	0.07065	4,550	163	0.81097	533.8
Pass 2						
Station						
0.00	791	0.09342	2,611	210	0.63544	13.54
15.00	674	0.11746	2,468	225	0.45027	19.08
30.00	553	0.14042	2,292	230	0.27315	25.48
45.00	431	0.15526	2,065	236	0.15876	37.13
Pass 3						
Station						
0.00	371	0.16025	1,385	240	0.12023	22.61
15.00	330	0.16417	1,325	244	0.09002	21.35
30.00	289	0.16676	1,261	246	0.07010	20.02
45.00	250	0.17046	1,203	250	0.04001	18.23

Drying Process Summary:

	Infeed	Output	
Moisture	1.00010	0.04001	
Solids (lb/hr)	27,000	27,000	
Water (lb/hr)	27,003	1,080	
Total (lb/hr)	54,003	28,080	
Evaporation (lb/hr)		25,923	
Exhaust Air Vol. =		63,720	ACFM
Heat Required[1] =		43,187,718	BTU/hr
Specific Th. Energy[1] =		1,666	BTU/lb evap
Th. Efficiency[1] =		0.5926	

[1]Basis for heat amount is Fuel G.C.V. (gross calorific value)

The following is an analysis of the foregoing data with an explanation of the advantages which inhere in the dryer design of the present invention.

FIRST PASS

In the dryer of the present invention the bulk of the moisture is removed in the outer (first pass) drum where the particles are held below their saltation velocities which, in this example, will vary from about 4,400 feet per minute when wet to 2,350 feet per minute when dry (Table 1, column 4). A high velocity differential period is employed in the first pass.

By contrast, in the conventional dryer, the wet particles are driven away from the heat source at a net forward velocity of approximately 600 feet per minute to the rear of the inner (first pass) drum (Table 2, column 4). Because the particles will travel this distance in under 6 seconds, there is little opportunity for transfer of heat to the particle or for transfer of moisture from the particle (Table 2, column 6). Even though the velocity differential is great, the duration is very short resulting in a low velocity differential period.

SECOND PASS

In the dryer of the invention, partially moist particles will begin to convey at a point in the intermediate (second pass) drum where their decreasing saltation velocities (due to decreasing density) balance with the air velocity. Those nearly dry particles will be conveyed at a low enough net forward velocity to provide time enough to completely remove their moisture. The already dry particles are being conveyed because their saltation velocities are less than the air velocity.

In the conventional dryer, the bulk of the material is dried in the intermediate (second pass) drum (Table 2, column 6). Notice that air velocities are below the minimum saltation velocity for both the dry and partially moist particles, throughout the second pass (Table 2, column 4). Here particles "settle out" and "drifting" occurs. There is a maximum material flow which will exist this pass; if a material flow greater than this is admitted into this region, plugging will occur with possible disastrous effects. Volatizing of the surface molecules of dry particles may result in either their decomposition causing an ensuing air pollution control problem, or the elevation of their surface temperatures to their flash points resulting in their combustion and an ensuing "dryer fire."

THIRD PASS

Material entering the inner cylinder (blending zone) of the dryer of the invention is quickly accelerated at the blending nozzle (Table 1, column 6). Lower humidity, temperature controlled air entering at this interface causes both a highly turbulent blending zone providing intimate contact with the near dry material and any additives or binding agents introduced here as well as providing a lower humidity region causing an increased partial pressure differential between the particle and its atmosphere resulting in the attainment of the desired moisture content without any additional heat requirement.

In the conventional dryer, the mass of particles (both dry and moist) will slowly advance (below saltation velocities) through the outer (final pass) drum, provided they were able to round the corner from the second pass to the final pass. The final moisture is removed here. While the bulk temperature of the solids appear favourable, dryer particle surface temperatures may be elevated to the 330 degree to 370 degree range near the entry of this pass because they were unable to exit the flow stream when adequately dried. Here again, volatization or combustion of these particles may occur. Finally, the dried material will be brought into contact with the exit conveying duct by lifting flights as the dryer rotates.

In sum therefore, greater velocity differential periods are maintained between the hottest gases and the wettest material in the dryer of the invention, providing more rapid heat and mass transfer by correctly utilizing the material to gas density relationship and holding the material below saltation velocity until dry.

When dry, a material will reach a saltation velocity. It is important at this point to provide a gas velocity sufficient to pick up the particle and pneumatically convey it out of the drying environment. The dryer of

the invention accomplishes this whereas a conventional drum allows the material to "settle out" which may result in "blue haze", plugging, or a dryer fire.

Increased efficiency is possible because of greater airflow through the dryer of the invention. On the other hand, an increased airflow through a conventional dryer merely results in more rapid advancement of the moist material away from the heat source and more intense packing at the point of material "drop out" from the flow stream.

We claim:

1. A multiple-pass product treating device comprising:

an elongated, normally horizontally disposed, axially rotatable body having means defining a plurality of elongated internal passageways intercommunicated to present a continuous, serpentine flow path through said body,

each of said internal passageways having a different effective cross-sectional area respectively;

means defining a product inlet oriented for initially directing product to be treated into a selected one of said passageways having a relatively large effective cross-sectional area;

means defining a product outlet in communication with another of said passageways having a relatively smaller effective cross-sectional area as compared with said one passageway,

said other passageway being disposed within and radially inboard of said one passageway; and

means for creating air currents within said body and along said flow path for conveying said product in a cocurrent fashion with said air currents along the flow path through said one passageway having said relatively large effective cross-sectional area, into and through said other passageway having said relatively small cross-sectional area, and out said product outlet.

2. The device of claim 1, including means for heating said air currents.

3. The device of claim 1, said passageway-defining means comprising a plurality of elongated, concentric drums, said one passageway being defined between the outermost and next adjacent inboard drum, and said other passageway being defined by the innermost drum.

4. The device of claim 1, including means for introducing an additive into said flow path separate from said product and air currents.

5. The device of claim 4, said additive introduction means comprising structure for delivery of said agent directly into said other passageway.

6. The device of claim 1, including flight means within said body and positioned along the length of at least a portion of said flow path for dispersing said product and assisting in the conveyance thereof.

7. The device of claim 1, said air current-creating means including induced draft fan means for inducing airflow within said body and along said flow path.

8. A multiple-pass dryer, comprising:

an elongated, normally horizontally disposed, axially rotatable body having an outermost drum and a plurality of substantially concentric internal drums of progressively smaller diameter, said drums cooperatively defining a plurality of elongated, substantially concentric internal passageways each having an entrance end and an exit end and being in communication with each other to present a continuous serpentine flow path through said body,

said outermost drum having an axial length substantially longer than the lengths of said internal drums to define, at one end of said body, a premixing zone, said zone being in communication with the outermost passageway defined between said outermost drum and the next adjacent inboard drum;

means defining a wet product inlet in communication with said premixing zone;

means for including a flow of heated air currents within said body and proceeding from said premixing zone and into and along said flow path first along said outermost passageway and then along radially inner passageways for conveying said initially wet product from said premixing zone into and along said flow path while simultaneously drying the product; and

means defining a dried product outlet in communication with the end of said flow path remote from said premixing zone.

9. The dryer of claim 8, including inwardly projecting flight means carried by said outermost drum in the region of said premixing zone.

10. The dryer of claim 8, said dryer being a three pass dryer with a pair of substantially concentric internal drums of progressively smaller diameter, there being wall means in covering relationship to the ends of said internal drums adjacent said premixing zone to prevent direct passage of air and product into said internal drums.

11. In a method of drying an initially wet product in a multiple-pass rotary drum dryer, said dryer presenting structure defining a plurality of elongated, internal passageways each having an entrance end and an exit end and having respective, generally parallel and horizontal longitudinal axes, said passageways being intercommunicated with each other to present a continuous, serpentine flow path, and wherein the product is introduced in particulate form into said flow path and conveyed therealong by induced hot air currents, the improvement which comprises directing said air currents and product particles first to a radially outboard passageway and thence to radially inboard passageway(s), and, during traversal of said particles and air currents along said flow path, increasing the average net velocity of both said air currents and particles of said product in each of said elongated passageways as said particles and air currents pass along said serpentine flow path.

* * * * *

APPENDIX E.

MEMORANDUM: FORMLADEHYDE EMISSIONS FROM WAFERBOARD PRESS OPERATIONS

MEMORANDUM

To: Leslie B. Evans, EPA/CPB (MD-13)

From: John H. E. Stelling and Katherine L. Wertz, Radian/RTP

Date: 7 July 1987, 17 July 1987 Rev. 1

Subject: Formaldehyde Emissions from Waferboard Press Operations

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Summary. At your request we have examined formaldehyde emissions from press operations at the waferboard facility in Olathe, Colorado. We have used data from particleboard manufacturing (as published by NCASI) and test data from the two sets of tests conducted at Olathe. The emissions ~~estimates~~ agree remarkably well for operations using formaldehyde-based resins as the polymer. Almost 90 percent reductions of formaldehyde emissions from the press vents can be realized by converting from formaldehyde-based resins (such as phenol-formaldehyde) to MDI. Based on test results of press vent emissions conducted at Olathe in March 1985 and June 1986, the formaldehyde emissions from press operations using P-F resins are 30 to 60 percent of the formaldehyde emissions from dryer operations.

Discussion. We looked at emissions from a 160 ton per day waferboard plant processing aspen. The press processes eight 8X16 panels simultaneously, with platen temperatures of 185-200^{o}C (365-392^{o}F). We computed the average density of waferboard from the June 1986 test report at Olathe; the density was computed at 37.05 lb/CF for a 3/4" 4X8-board weighing 74.1 pounds. This density was used to evaluate emission rates of formaldehyde from press operations when considering emission factors in terms of lb/MSF.

Emissions data were taken from NCASI Technical Bulletin 503 (Sept. 1986). The report examined emissions from different flakeboard mills using different resins. (Flakeboard is assumed to be similar to waferboard.) Mill A processes aspen, the same wood species processed at Olathe. The data for Mill A represent three blends of phenol-formaldehyde (P-F) resins. P-F resins are used in the industry because of superior performance in external applications such as roofing. The older urea-formaldehyde resins are only appropriate for interior applications such as in furniture. MDI is another popular choice as a waferboard resin. One comparison presented in this memorandum is between P-F resins and MDI.

The data on Mill A represent pounds of formaldehyde released for every actual 1000 SF of waferboard (lb/MSF HCHO), considering the area of one side

only. No correlation was found between the amount of formaldehyde emitted and process parameters. The data presented in the following table indicate that emissions vary with the resin formulation, but no data are available on the excess formaldehyde content of the resins or on the degree of polymerization.

Table 1. Press Emissions of Formaldehyde.

Resin	Mill	Press Temperature, °F	Percent Resin	lb/MSF HCHO
A	A	400	4.8	0.33
B	A	400	4.8	0.56
C	A	400	4.8	0.53

Daily emission rates were computed based on a 160 TPD production rate of waferboard and the three emission factors presented in the table above. The resulting emission rates (45.6, 77.4, and 73.4 lbs HCHO/day) were averaged to yield a daily emission rate of 65.4 lbs HCHO.

The HCHO emission rate for press operations determined from emission testing at Olathe were then compared to this average daily estimate. The June 1986 test at Olathe indicated that the combined emissions from both press vents were 6.56 lb/day when the plant was operating with MDI as the binding resin. The formaldehyde emissions from the press vents during the March 1985 tests were approximately an order of magnitude higher at 62.2 lb HCHO/day. The latter value indicates that the plant might have been operating with P-F resins during the early test since the emissions rate is very close to the estimate based on the flakeboard data.

Using the 65.4 lb HCHO/day emission rate, the change from P-F resins to MDI resulted in a 90 percent decline in formaldehyde emissions from the press vents. Conversely, if P-F resins are substituted for the MDI currently in use, press emissions of formaldehyde might increase ten fold.

Comparison to Total Plant Emissions. It is also important to compare press emissions to wafer dryer emissions. Our review of the Olathe facility indicated that the dryer represents the highest single emission point for formaldehyde. Furthermore, an olfactory check of press steaming indicated no large presence of formaldehyde's acrid, astringent quality. We compared dryer formaldehyde emissions from both tests with press formaldehyde emissions during the most recent test. Emissions ranged from 105 lb HCHO/day for the March 1985 test to 205.8 lb HCHO/day during the June 1986 test. Table 2 presents a comparison of formaldehyde emissions from plants operating with either P-F resins or MDI. This is a hypothetical comparison since dryer emissions can certainly vary.

Table 2. Plantwide Formaldehyde Emissions
(lb HCHO/day)

Equipment	P-F Resins	MDI Resin
Dryer	155	155
Press	65	6.6
TOTAL	220	161.6

Using the values in Table 2's hypothetical example, press emissions of formaldehyde represent about 30 percent of total formaldehyde emissions plantwide. In shifting to MDI resin, the percentage of total plantwide formaldehyde emissions attributable to the press operations is reduced to about 4 percent. An overall reduction of almost 27 percent is achieved for formaldehyde emitted from the plant when considering the change from P-F resins to MDI.